Weather Event Simulator

Winter Weather Simulation Guide: 31 January - 1 February 2008

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1. The 31 January - 1 February 2008 Event Overview

On 31 January through 1 February 2008, a significant winter storm brought widespread heavy snowfall to east-central Missouri through central and northern Illinois. The heaviest snow (>6") fell in a band from St. Louis, MO to Chicago, IL and an embedded band of snow, with amounts between 8 and 12 inches, occurred from northeast of St. Louis, MO to Springfield, IL (Fig. 1.1). Snow began in the late morning on 31 January over the southwest portions of the St. Louis, MO County Warning Area (LSX CWA) and spread northeast through the afternoon into the Lincoln, IL County Warning Area (ILX CWA).

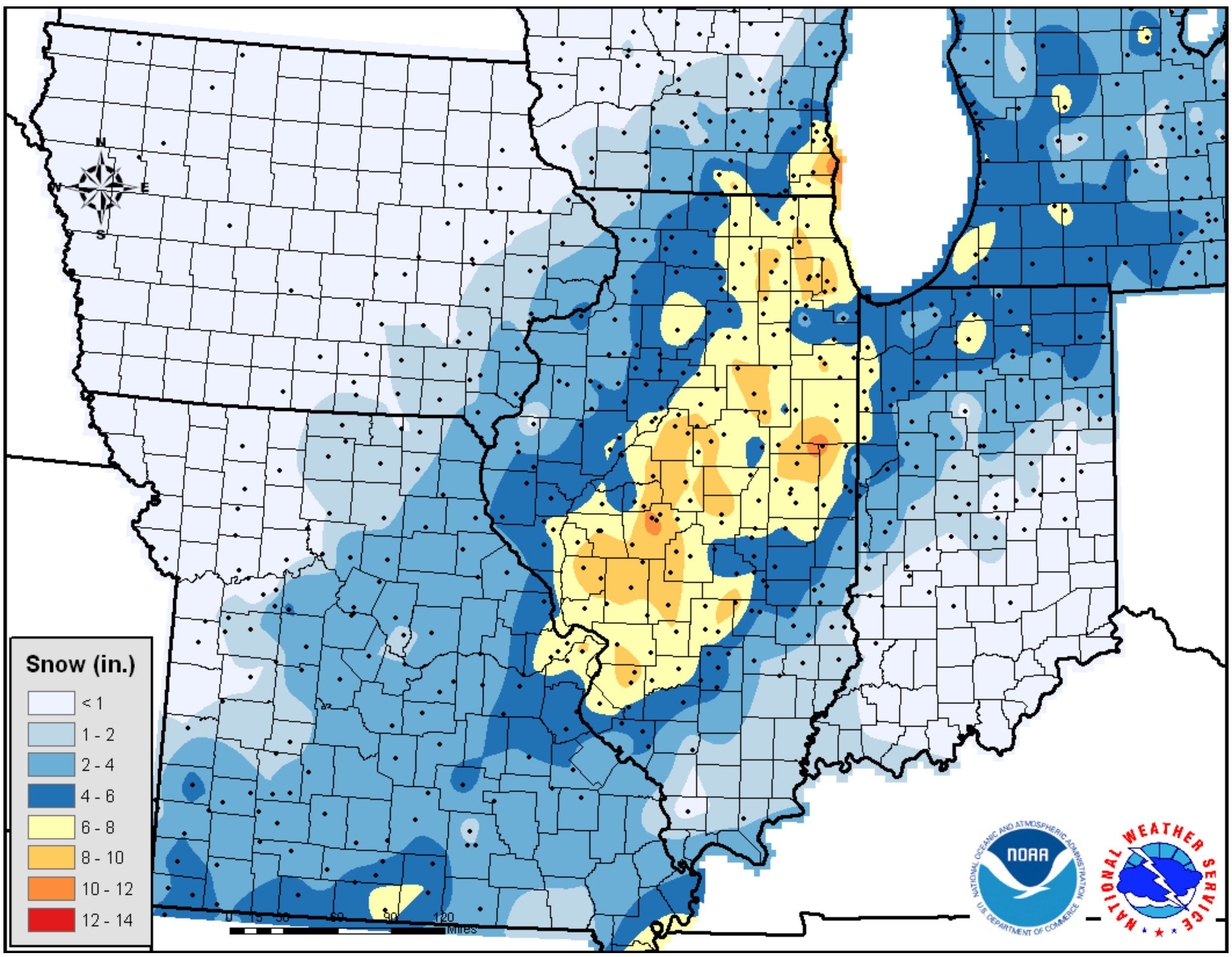

Fig. 1.1. COOP snowfall from NCDC for the 72-h period ending at 1200 UTC 20080202.

Initially forced by an unorganized warm conveyor belt, the snow shield was light with embedded moderate bands through most of the day on 31 January (Fig. 1.2, top left). As the mid-level short-wave trough strengthened into the late evening and overnight on

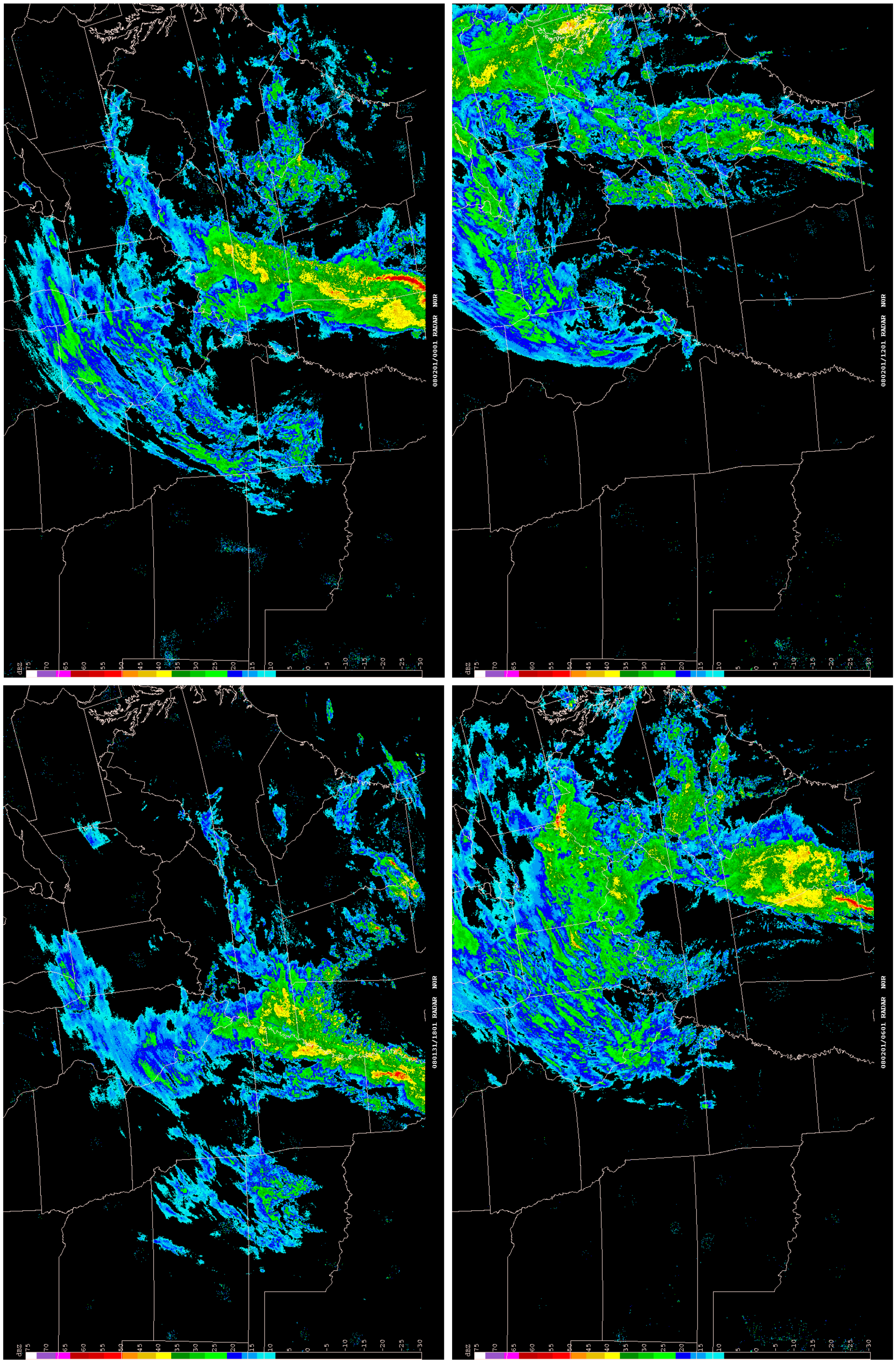

Fig. 1.2. WSR-88D 1 km base reflectivity at 1801 UTC 31 January 2008 (top left), 0001 UTC 1 February 2008 (top right), 0601 UTC 1 February 2008 (bottom left), and 1201 UTC 1 February 2008 (bottom right).

1 February 2009, the warm conveyor belt/TROWAL became better organized which lead to an increase in snow coverage and intensity (Fig 1.2, bottom left). In the St. Louis metropolitan area, snowfall rates approached 2” per hour which resulted in rapid accumulations. The St. Louis Weather Forecast Office in Weldon Springs, MO received 3.6” of snow between 0545 UTC and 0710 UTC. Numerous reports of thunder and lightning with the snow in the eastern portion of the LSX CWA and to the north near Springfield and Decatur, IL showed the convective nature of the mesoscale snowbands. By 1500 UTC the TROWAL and deformation zone snow moved to the northeast of both the LSX and ILX CWAs. The North American Regional Reanalysis (NARR) and WSR-88D 1 km base reflectivity were utilized in the following synoptic-scale and mesoscale analysis.

1.1 Synoptic Analysis

At 1200 UTC 30 January 2008, a strong mid-level shortwave and associated surface low were moving northeastward through southeastern Canada. The attendant cold front brought sub-freezing temperatures as far south as northern Louisiana, central Mississippi, and northern Alabama. In St. Louis, MO a record high temperature of 73°F was set on 29 January and by 0000 UTC 30 January the temperature was 17°F. At this time a new short-wave trough was entering the Pacific Northwest and would move southeastward into the southern Rockies by 0000 UTC 31 January. At the surface and lower troposphere, the lee-side trough strengthened and moved into the Texas Panhandle.

By 1200 UTC 31 January, the 1008-mb surface low continued to move east and was located over northern Texas (Fig. 1.3, top left). The surface low and 850-mb low were responsible for a broad area of south southeasterly flow at the surface and south southwesterly flow at 850 mb. These were responsible for increasing dew points and precipitable water values over eastern Texas and the Lower Mississippi Valley. At 500 mb, the positively-tilted shortwave trough continued to dig to the east-southeast and was located over west Texas (Fig. 1.3, bottom left). The broad 300-mb 110-kt jet streak extended downstream of the long-wave trough from Texas northeast to New England (Fig. 1.3, bottom right).

The surface low continued to move to the east-southeast and was located over western Mississippi at 0000 UTC 1 February (Fig. 1.4, top left). The 850-mb low also continued east and was located over northeastern Arkansas. In addition, the synoptically forced low-level jet streak strengthened as the 850-mb low moved eastward and the height gradient tightened (Fig. 1.4, top right). At 500 mb, synoptic-scale forcing was increasing across the Mid-Mississippi River Valley with the vigorous short-wave trough axis oriented from north to south from eastern Kansas into eastern Texas (Fig 1.4, bottom left). In addition, as the 300-mb trough transitioned from positive to neutral tilt over the central Plains the downstream jet streak increased to over 150 kts (Fig. 1.4, bottom right). The enhanced ageostropic flow in the entrance region of the upper-level jet further contributed to increasing large-scale lift over the Mid-Mississippi River Valley.

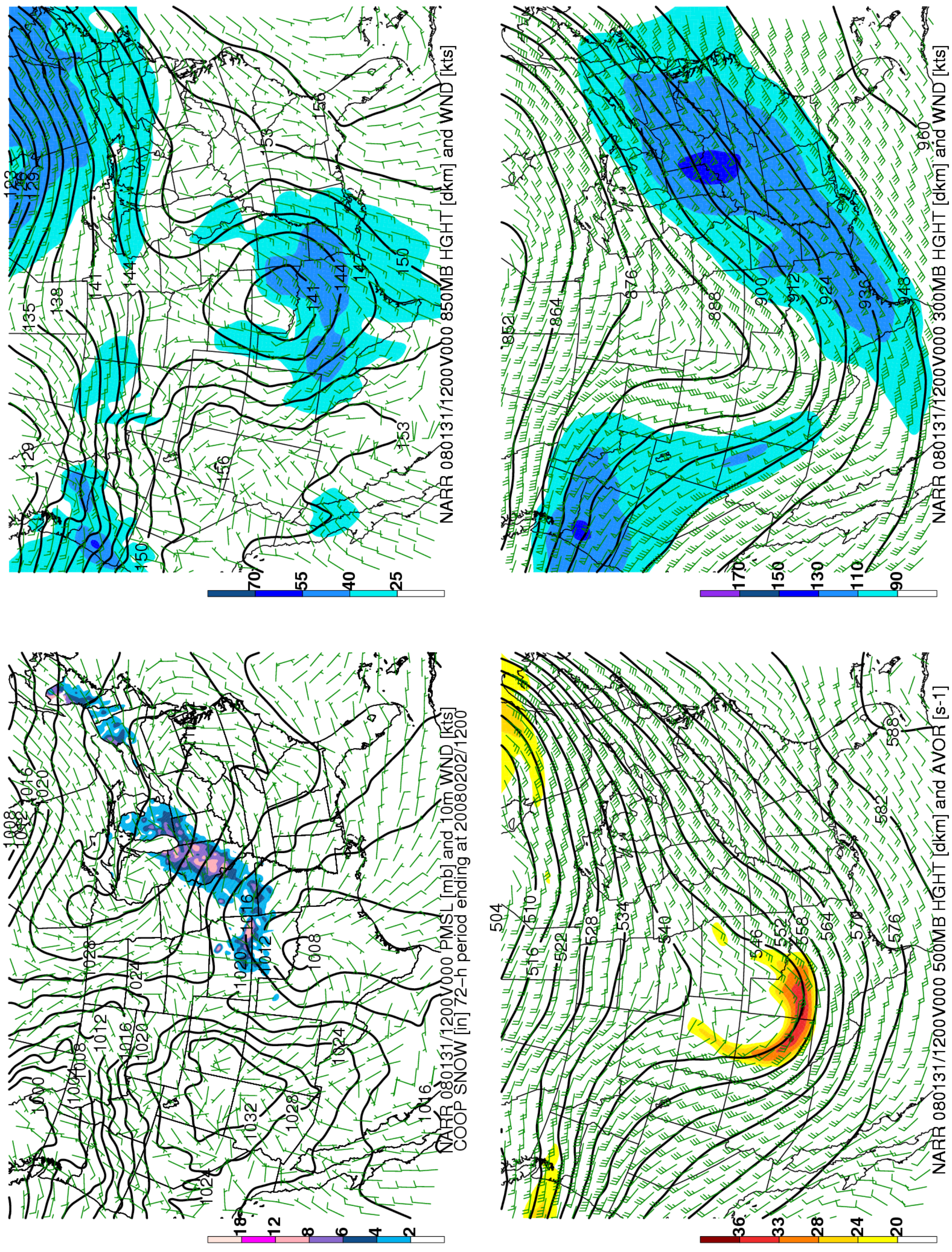

Fig. 1.3. NARR 1200 UTC 31 January 2008 PMSL [black,mb], 10m wind [barbs,kts], and COOP snowfall for the 72-h period ending at 1200 UTC 20080202 [shaded,in] (top left); 850-mb height [black,dm], isotachs [shaded,kts], and wind [barbs,kts] (top right); 500-mb height [black,dm], wind [barbs,kts], and absolute vorticity [shaded,s-1] (bottom left); 300-mb height [black,dm], isotachs [shaded,kts], and wind [barbs,kts] (bottom right).

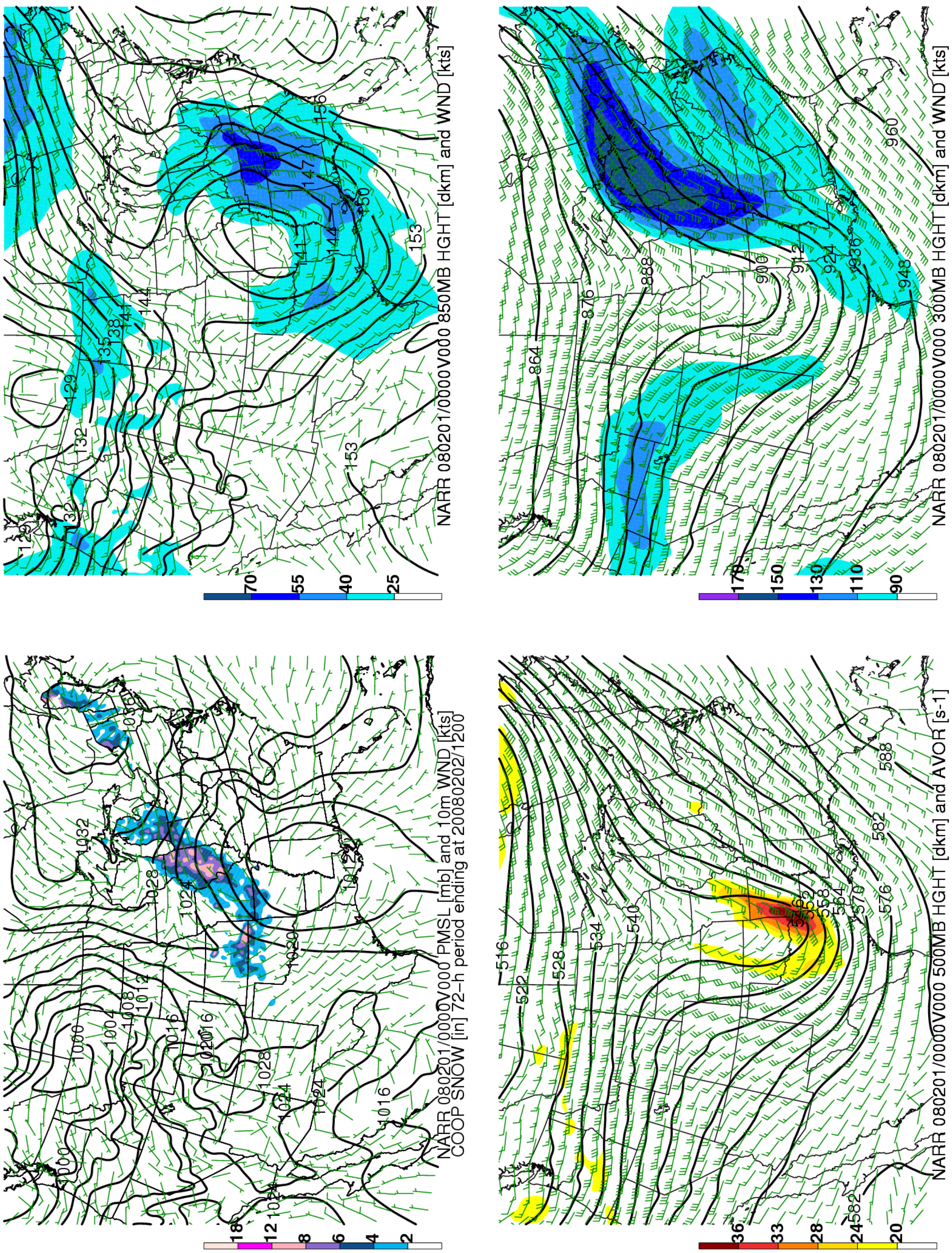

Fig. 1.4. NARR 0000 UTC 1 February 2008 PMSL [black,mb], 10m wind [barbs,kts], and COOP snowfall for the 72-h period ending at 1200 UTC 20080202 [shaded,in] (top left); 850-mb height [black,dm], isotachs [shaded,kts], and wind [barbs,kts] (top right); 500-mb height [black,dm], wind [barbs,kts], and absolute vorticity [shaded,s-1] (bottom left); 300-mb height [black,dm], isotachs [shaded,kts], and wind [barbs,kts] (bottom right).

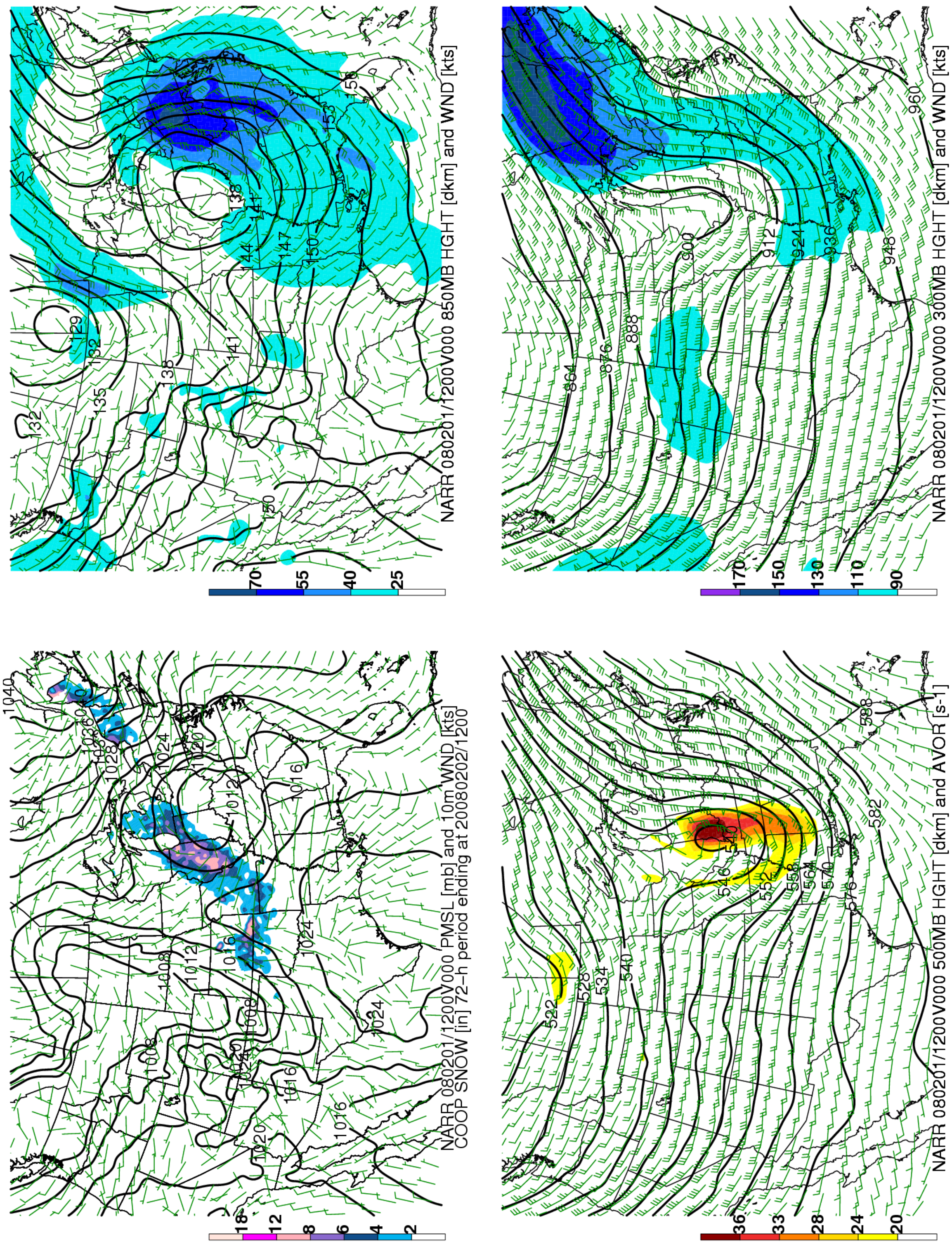

Fig. 1.5. NARR 1200 UTC 1 February 2008 PMSL [black,mb], 10m wind [barbs,kts], and COOP snowfall for the 72-h period ending at 1200 UTC 20080202 [shaded,in] (top left); 850-mb height [black,dm], isotachs [shaded,kts], and wind [barbs,kts] (top right); 500-mb height [black,dm], wind [barbs,kts], and absolute vorticity [shaded,s-1] (bottom left); 300-mb height [black,dm], isotachs [shaded,kts], and wind [barbs,kts] (bottom right).

The modest 1012-mb surface low had moved into east-central Indiana by 1200 UTC 1 February (Fig. 1.5, top left). During the previous 12 hours, and for the majority of the surface low's life cycle, the surface low did not deepen dramatically. In contrast, the 850-mb low did strengthen over the previous 12 hours as it moved to the north-northeast from northeastern Arkansas to west-central Indiana (Fig. 1.5, top right). This was most likely in response to strong mid- to upper-level synoptic scale forcing as the mid-level and upper-level troughs transitioned from neutral to negative tilt (Fig. 1.5, bottom left and right).

1.2 Mesoscale Analysis

Much of the precipitation that fell between 1800 UTC 31 January and 0000 UTC 1 February in the LSX and ILX CWAs was driven by increasing synoptic scale lift (Fig. 1.3 and Fig. 1.4) and a broad warm conveyor belt (Fig. 1.6, top left). This led to a large north to south oriented area of precipitation with embedded bands in the northern portion of the LSX CWA (Fig. 1.2, top left). By 0300 UTC 1 February, the warm conveyor belt became better organized and the trough of warm air aloft (TROWAL) began to form as the western-most extension of the warm conveyor belt began to turn counterclockwise into central Missouri. This is evident by the ridge in the pressure field on the 298 K isentropic surface (Fig. 1.6, top right). WSR-88D 1 km base reflectivity showed an increase in coverage and intensity of radar reflectivity over the eastern half of the LSX CWA and over the ILX CWA as multiple bands of >25 dBZ were evident in the deformation zone shield of precipitation (Fig. 1.6, bottom left). In addition, between 0600 and 0900 UTC 1 February the TROWAL signature on the 298 K isentropic surface continued to organize as the isobars showed a more defined ridge of high pressure from eastern Kentucky and southern Ohio westward to east-central Missouri (Fig. 1.6, bottom left and right).

As the TROWAL airstream turned cyclonically to the northwest of the surface cyclone, a region of deformation (not shown) developed and frontogenesis at mid levels increased. The system continued to strengthen as the mid-level shortwave became negatively titled. A persistent band of frontogenesis at 600 mb (Fig. 1.7), coupled with the TROWAL axis, contributed in the rapid expansion and intensity of the radar reflectivity within the deformation zone. The presence of conditional symmetric instability (CSI) is also apparent between 0000 and 0900 UTC. Fig. 1.7 shows a consistent region of 600-500 mb layered average EPV less than 0.25 PVU along and to the southeast of the axis of frontogenesis. In addition, upright instability was located over eastern Missouri and Illinois with 200 J kg MUCAPE which was most likely responsible for the convective snow observed during this event. Banacos (2003) indicates that multiple bands of heavy snow, like those evident in the bottom left of portion of Fig. 1.2 across Missouri and Illinois, occur when the 700-500 mb lapse rate is either unstable or moist neutral. A NARR sounding taken at Lincoln, IL at 0600 UTC 1 February shows several features that would point to multiple bands of heavy snow (Fig. 1.8). The sounding depicts a deep isothermal lapse rate from the surface to 650 mb; above this layer, a slightly unstable moist neutral lapse rate exists to 400 mb. Finally, a col point is present at low levels with unidirectional wind shear above.

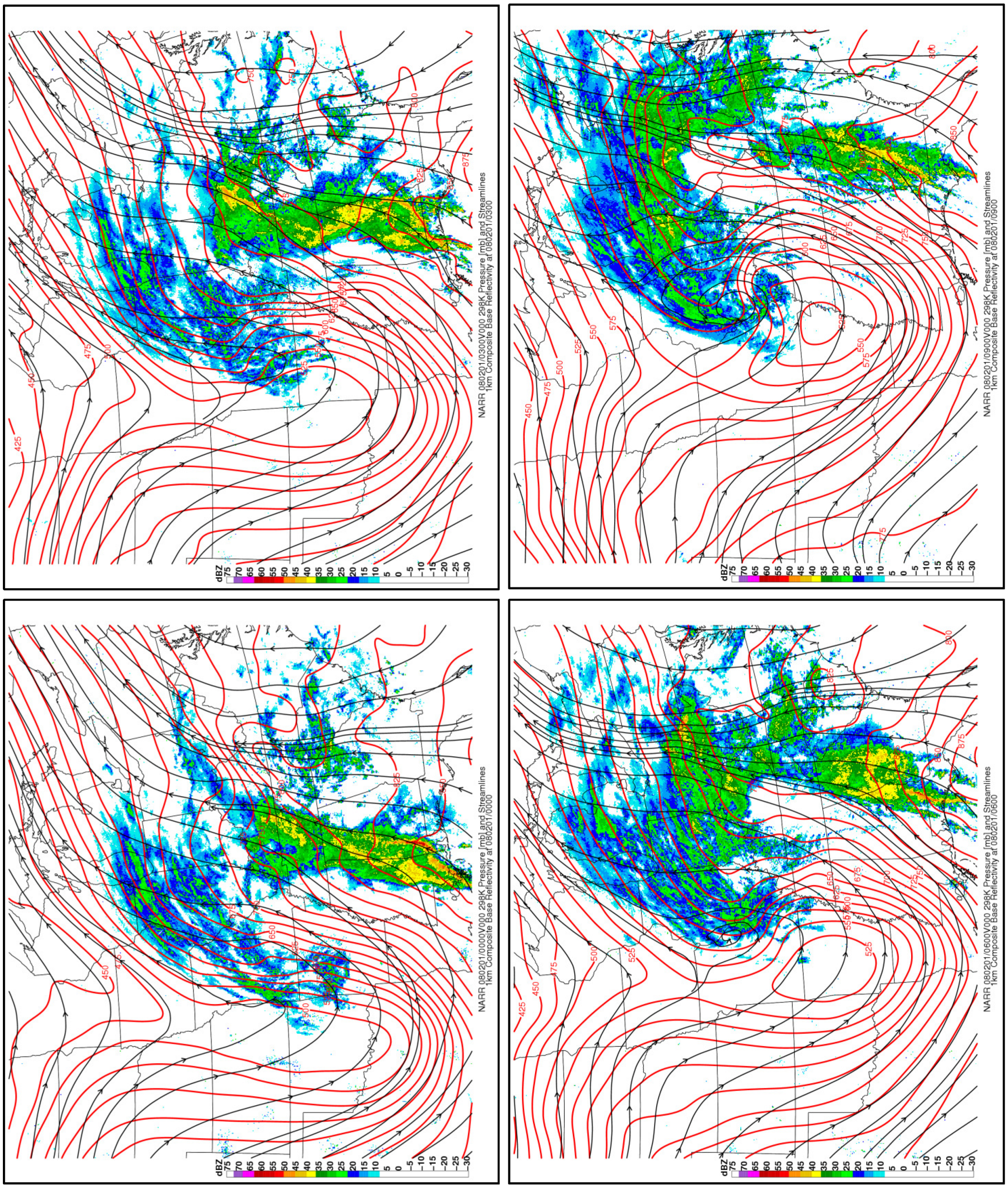

Fig. 1.6. NARR 298K streamlines [black], isobars [red, mb], and WSR-88D 1 km base reflectivity at 0000 UTC 1 February 2008 (top left), 0003 UTC 1 February 2008 (top right), 0600 UTC 1 February 2008 (bottom left), and 0900 UTC 1 February 2008 (bottom right).

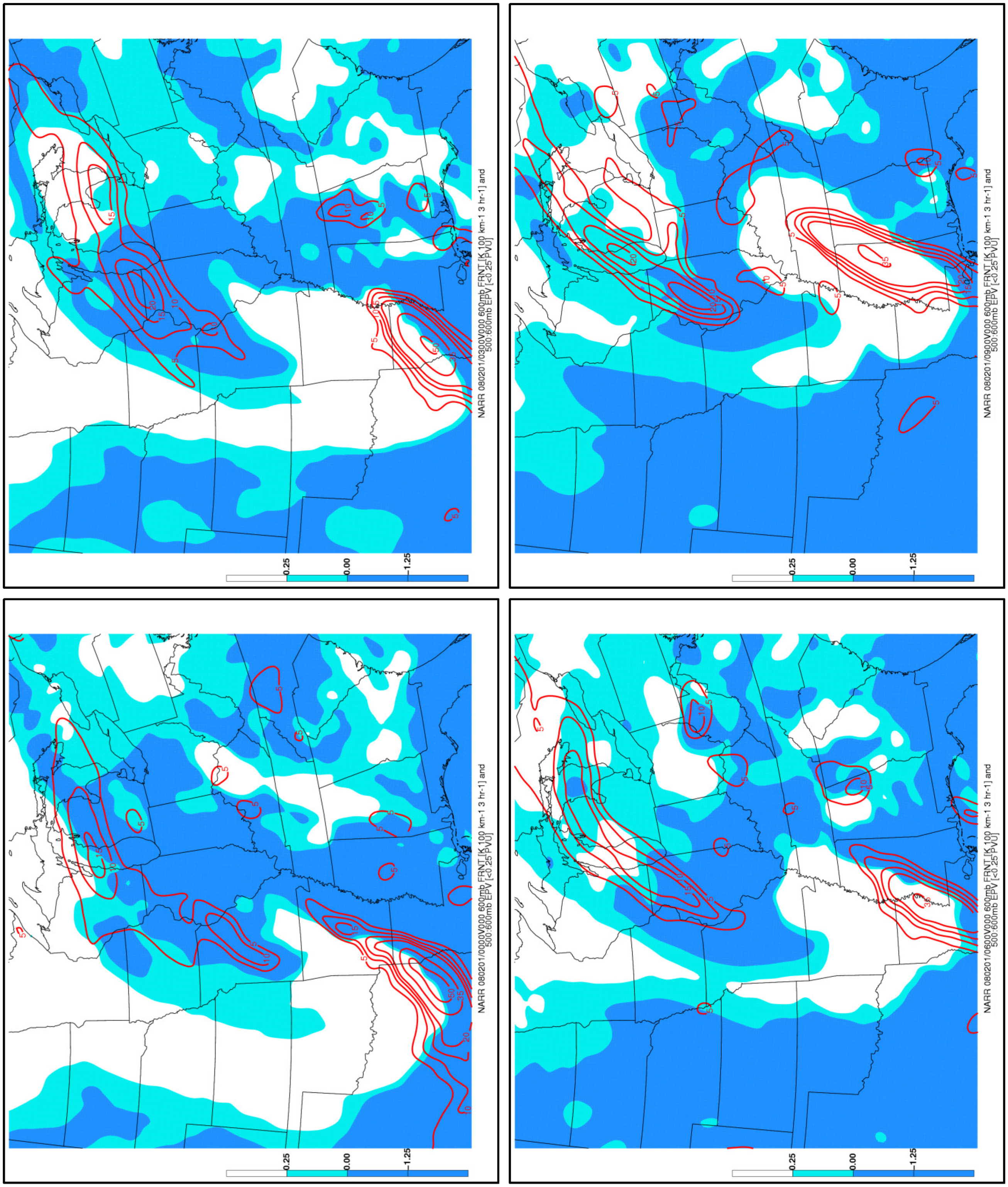

Fig. 1.7. NARR 600-mb frontogenesis [red, K 100 km^{-1} 3 hr^{-1}] and 500:600-mb EPV [shaded blue, <0.25 PVU] at 0000 UTC 1 February 2008 (top left), 0003 UTC 1 February 2008 (top right), 0600 UTC 1 February 2008 (bottom left), and 0900 UTC 1 February 2008 (bottom right).

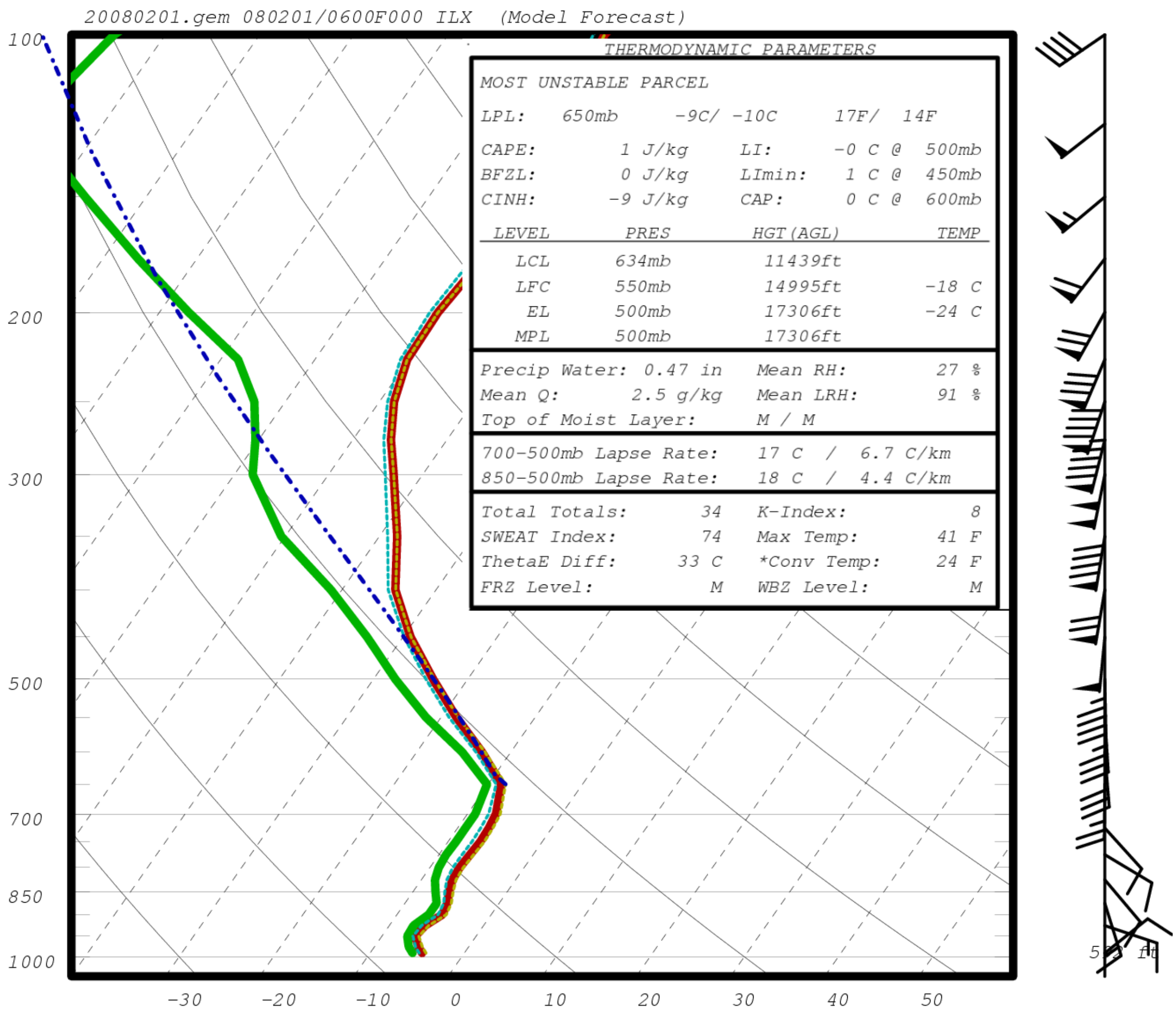

Fig. 1.8. NARR skew T-log p sounding for Lincoln, IL at 0600 UTC 1 February 2008. Figure inset shows the thermodynamic parameters of the most unstable parcel.

2. Simulation Strategies

Two simulation examples are included in this section for the the 31 January - 1 February 2008 case. Simulation 1 focuses on the watch phase in the LSX CWA, and it should precede simulation 2. Simulation 2 focuses on the warning phase in the LSX CWA.

The simulation examples are provided as a guide, and the Science and Operations Officer (SOO) should modify these or create new ones as he or she sees fit. Each simulation provides an introduction, a list of the skills important to this case and winter weather forecasting, and time for a short debrief for a review of key concepts and feedback by the evaluator. However, feedback can and should be provided to the trainee throughout the simulation as sections are completed.

2.1 Simulation 1 - LSX Winter Weather Watch Phase

Overview:

This simulation focuses on the challenge of recognizing the scope of the heavy snow potential in the LSX CWA for a major winter weather snow event that was forced by well organized synoptic-scale lift and mesoscale processes. The start time for simulation 1 is 0500 UTC 30 January 2008. At this time there was considerable agreement that a major winter storm would affect at least a portion of the LSX CWA. However, between the deterministic models, there was uncertainty in the track of the mass fields and QPF. The primary focus of simulation 1 will be: 1) the uncertainties that are associated with winter weather events, 2) on how a conceptual model can assist in the forecast process, and 3) how past research can assist the forecaster in determining where the axis of heavy snowfall will occur.

The SOO shall provide the trainee copies of Goree and Younkin (1966) and Browne and Younkin (1970) to read or review before the start of the simulation. The simulation is about 36 hours before the onset of snow (snow began around 1700 UTC 31 January 2008) in St. Louis, MO. Simulation 1 has been developed to be taken before simulation 2, therefore it is important to wait till after simulation 2 is complete to discuss what actually occurred with this event. The schedule for the trainee, evaluation criteria, and trainee worksheet with brief discussion points are included below.

Schedule for trainee:

(30 min): Deterministic and SREF ensemble analysis.
(10 min): Overview of Goree/Younkin/Browne Technique.
(5 min): HPC product review.
(15 min): Issue winter weather products.

(30 min): Deterministic and SREF ensemble analysis.

• This section utilizes IC Winter 6 Lesson 6.3 - Using Ensembles in Winter Weather Forecasting

• The trainee should become familiar with the LSX CWA heavy snow conceptual model. The conceptual model was generated using NARR fields from 30 southwest to northeast oriented heavy snow swaths in the LSX CWA. For more information, the SOO is directed to the references at the end of this simulation guide.

• The trainee should use and refer to the LSX heavy snow conceptual model as he or she diagnoses the forecast using the deterministic operational model guidance on the WES. For more information on the LSX CWA heavy snow climatology see http://www.eas.slu.edu/CIPS/PRESENTATIONS/LSXWWW08_Gosselin.zip

• The trainee should compare the current deterministic forecasts on the WES with the heavy snow climatology to determine if the track of the mass fields are favorable for heavy snow in the LSX CWA.

• Using the WES, the trainee should identify areas of uncertainty in forecast variables. In particular, variability in the surface, 850-mb, and 500-mb mass fields.

• The trainee should also identify the primary precipitation type.

• Finally, the trainee should identify whether there are high probabilities for significant amounts of precipitation and snow (using a climatologically favored SLR of 12:1 [www.eas.slu.edu/CIPS/SLR/slrmap.htm]).

<u>Discussion Points</u>

• Despite differences in the mass fields, wind fields, and QPF from the deterministic models, the trainee should be aware that the synoptic fields in the current forecast resemble southwest to northeast oriented heavy snow events over the past 28 years in the LSX CWA. 850-mb and surface low tracks are very similar to the conceptual model for heavy snow in the LSX CWA.

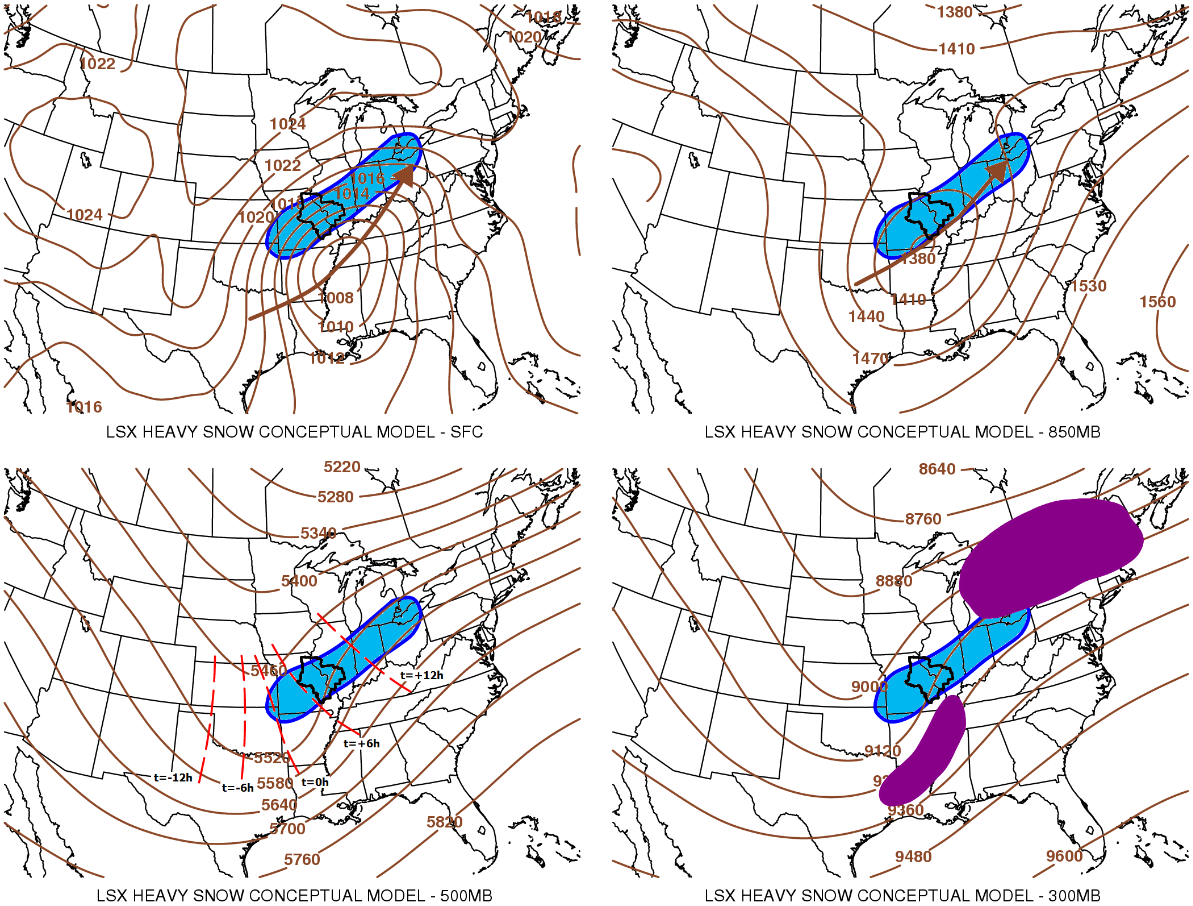

Fig. 2.2 LSX CWA heavy snow conceptual model. MSLP with track [brown, mb], top left; 850mb HGHT with track [brown, m], top right; 500mb HGHT [brown, m] with trough progression [red, dashed], bottom left; and 300mb HGHT [brown, m] with jet cores [purple, shaded], bottom right. Area of heaviest snow is shaded [blue] in each panel.

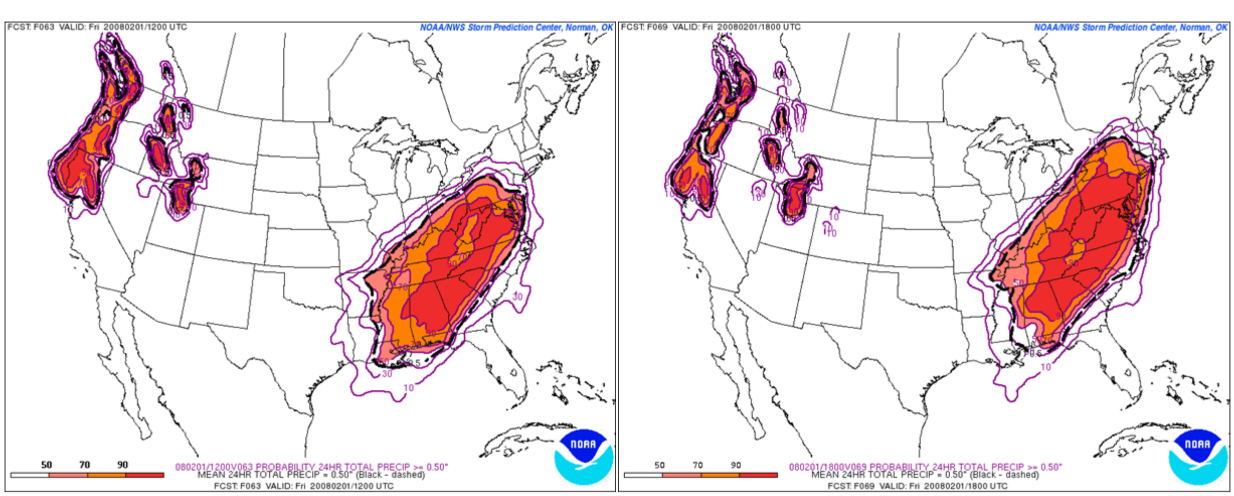

Fig. 2.3 SREF 63-h (left) and 69-h (right) forecast of probability of 24-h precipitation > 0.5" [shaded] and mean 24-h precipitation 0.5" [black dashed] valid at 1200 (left) and 1800 (right) UTC 01 February 2008.

• The trainee should note there is significant spread with the 500-mb shortwave both in intensity and speed (F063).

• The trainee should identify that the primary precipitation type in the LSX CWA will be snow based on model soundings and partial thickness.

• Warning criteria snowfall in the LSX CWA is 6” and the trainee should document that there are low probabilities for warning criteria snowfall in the LSX CWA based on low probabilities of 24-h precipitation > 0.5” (or > 6” snowfall using a SLR of 12:1). This guidance conflicts with the conceptual model for heavy snow in the LSX CWA.

(10 min): Overview of Goree/Younkin/Browne Technique.

• During this portion of the simulation, the trainee should review the summary of the research of Goree and Younkin (1966) and Browne and Younkin (1970).

(5 min): HPC product review.

• During the HPC product review, the trainee should review the most recently issued HPC deterministic snow forecast at 0650 UTC 30 January 2008 and the previous forecast at 1825 UTC 29 January 2008.

• The trainee should determine if there are any major differences between the current and previous HPC forecasts.

• The trainee should keep in mind the previous but more importantly the current HPC forecast when completing the remainder of this simulation.

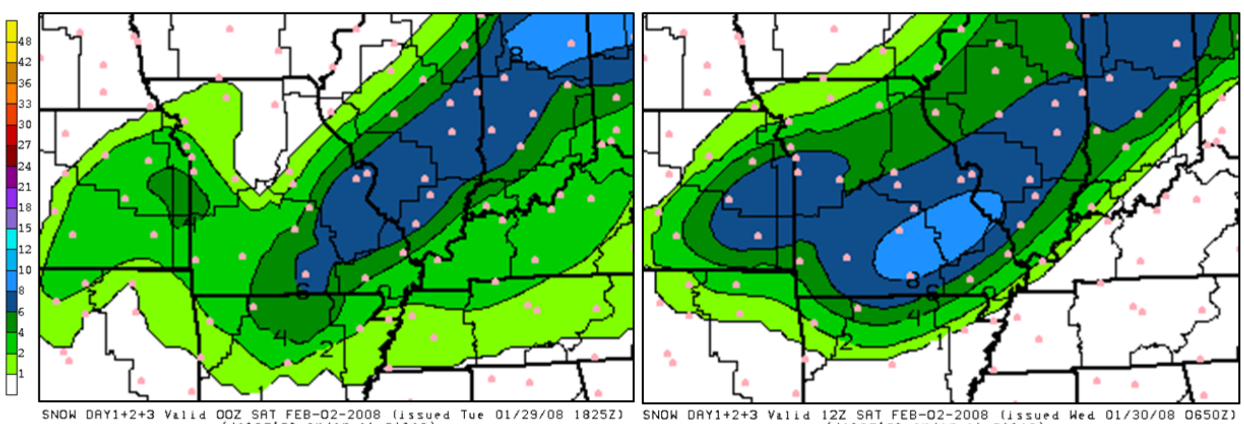

Fig. 2.1 HPC Winter Weather Desk deterministic forecasts issued at 1825 UTC 29 January 2008 and 0650 UTC 30 January 2008.

Discussion Points

• In the most recent HPC deterministic forecast, the northern extent of the greater than 6" contour has shifted slightly to the north while the southern edge has remained consistent. However, the southern snowfall gradient has become tighter on the southern edge of the snow swath. The northeastern extend of the greater than 6" contour has shifted to the northwest and now covers most of southern lower Michigan.

• Amounts have not changed dramatically since the previous forecast, however there is now a greater than 8" contour over the eastern portions of the SGF CWA and over southern portions of the LSX CWA.

(15 min): Issue winter weather products.

• The trainee should determine if all or portions of the LSX CWA should be considered for a winter storm watch. In addition to outlining the counties to be included in the winter storm watch, the trainee should draw their forecast snowfall amounts. Winter storm watch criteria is provided in the appendix for the LSX CWA.

• After becoming familiar with the research of Goree and Younkin (1966) and Browne and Younkin (1970), the trainee should be able to state the techniques and when they should be utilized when forecasting the approximate location of the heavy snow swath axis.

• Using the provided 850-mb low center composite chart from the 0000 UTC 30 January 2008 model runs, the trainee should identify the approximate location of the heavy snow swath axis using the approaches of Goree and Younkin (1966) and Browne and Younkin (1970).

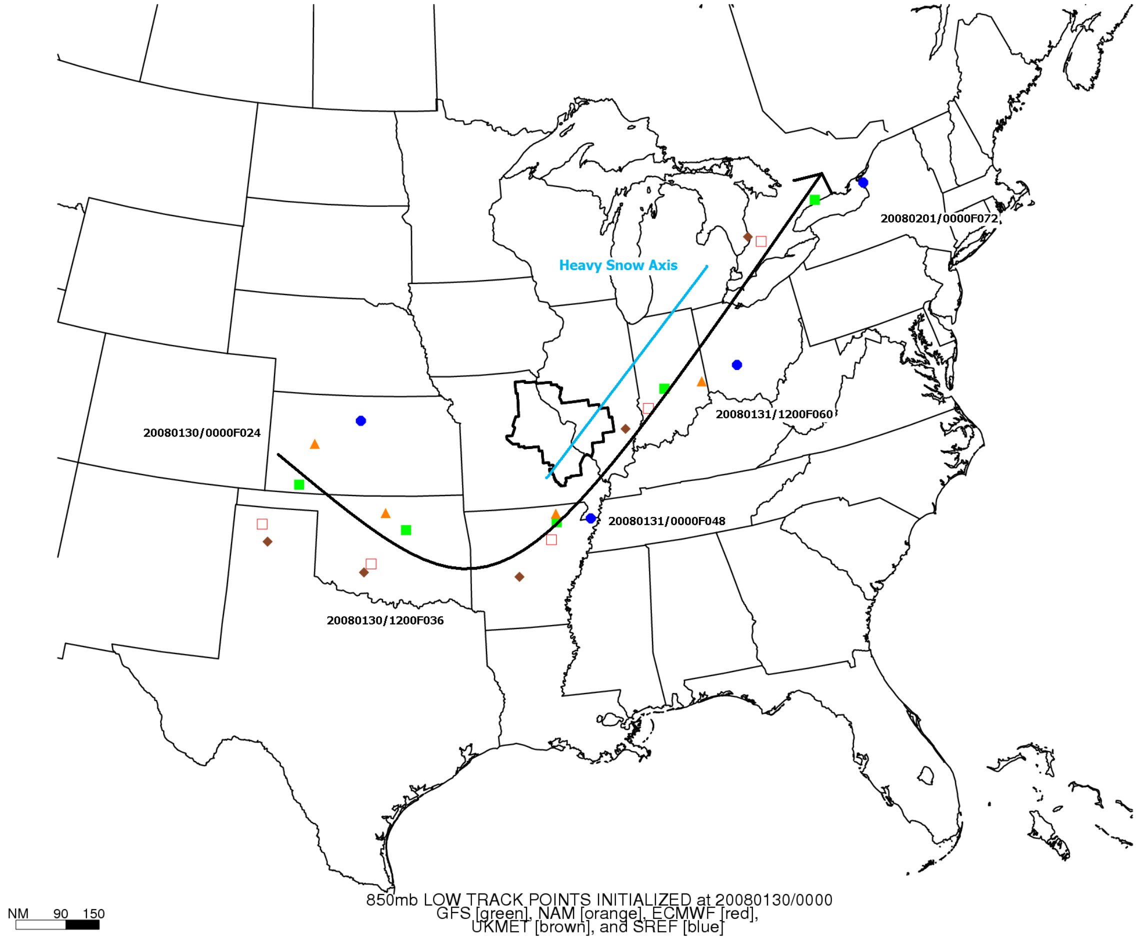

Fig. 2.4 850mb low centers initialized at 0000 UTC 30 January 2008 and valid for F024, F036, F048, F060, and F072. GFS [green squares], NAM [orange triangles], ECMWF [red squares], UKMET [brown diamonds], and SREF [blue octagons].

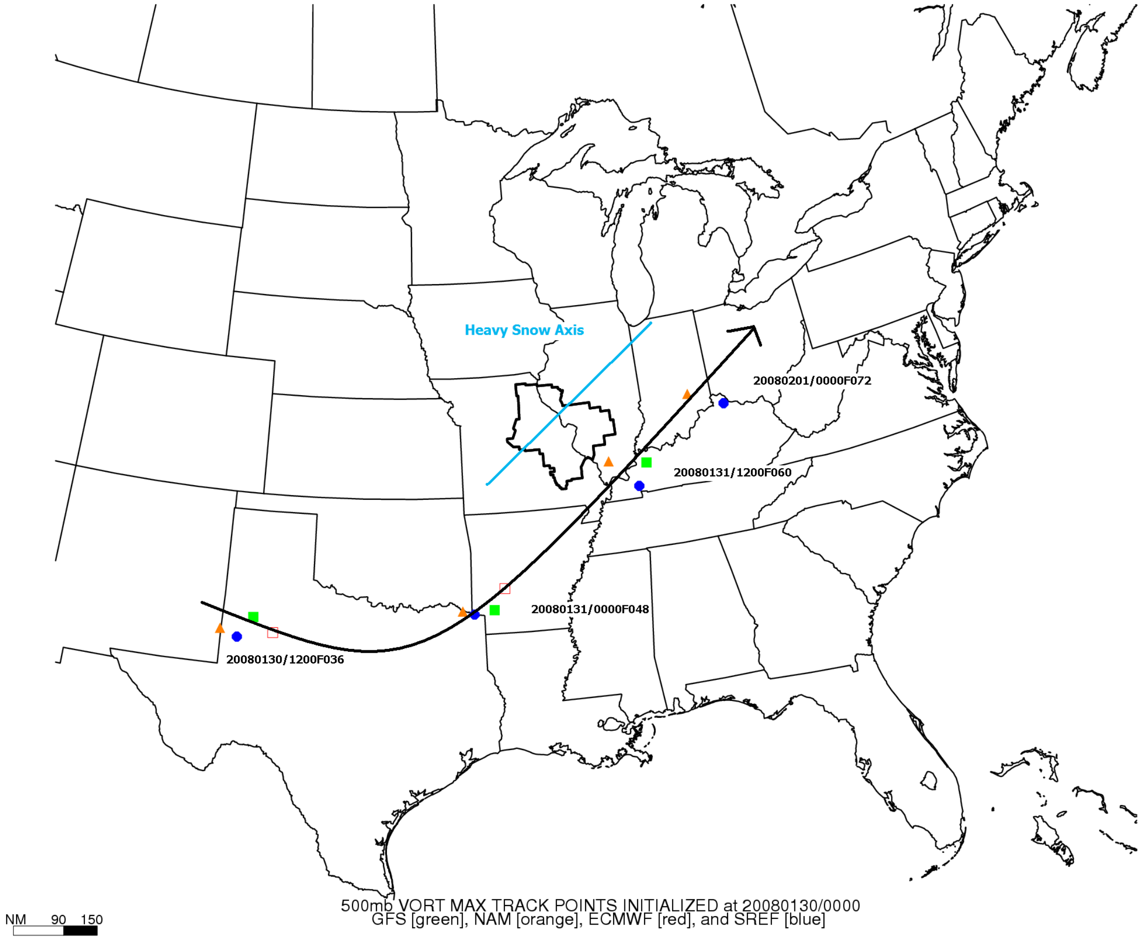

Fig. 2.5 500mb vorticity centers initialized at 0000 UTC 30 January 2008 and valid for F036, F048, F060, and F072. GFS [green squares], NAM [orange triangles], ECMWF [red squares], UKMET [brown diamonds], and SREF [blue octagons].

Discussion Points

• The trainee should understand that the approximate location for the axis of the heavy snow swath will be ~150 nm to the left of the 500-mb vorticity maxima. This method should be used when the 500-mb trough or low is deepening with time. When using the 850-mb low track, the heavy snow swath axis is 90 nm to the left of the 850-mb low track. Again, this method should be utilized when the 850-mb low is deepening with time. The trainee should state that these methods should be used together when both the 500-mb and 850-mb lows are deepening with time.

• Using the provided 850-mb low center composite chart from the 0000 UTC 30 January 2008 model runs, the trainee should place the heavy snow swath axis from southeast of St. Louis, MO to southwestern lower Michigan.

• Based on the information in this simulation, the trainee should considering issuing winter storm watches for portions or the entire LSX CWA. Since the lower-level mass fields will be organizing and strengthening in the vicinity of the LSX CWA, the trainee should be aware that confidence in snow amounts and location should be low due to the uncertainty in how these mass fields will evolve. However, there is a good probability of a band of heavy snow somewhere in the LSX CWA based on the application of the conceptual model.

2.2 Simulation 2 - LSX Winter Weather Warning Phase

Overview:

This simulation focuses on the challenge of recognizing the relationship between synoptic and mesoscale forcing as they relate to the ingredients based methodology for forecasting heavy precipitation and identifying the TROWAL on isentropic surfaces. The start time for simulation 2 is 0500 UTC 31 January 2008. At this time there continued to be considerable agreement that a major winter storm would affect at least a portion of the LSX CWA. Once again, HPC Winter Weather Desk deterministic snow forecasts have just been issued that increase the amount of snow across the southern portion of the LSX CWA.

The simulation is about 12 hours before the onset of snow (snow began around 1700 UTC 31 January 2008) in St. Louis, MO. Simulation 2 has been developed to be taken after simulation 1, however both simulations can be completed independent of each other. The schedule for the trainee, evaluation criteria, and discussion points are included below.

Schedule for trainee:

(30 min): Deterministic model analysis - Ingredients based methodology for forecasting heavy precipitation.
(15 min): Mesoscale diagnosis: TROWAL.
(5 min): HPC internal winter weather product review.
(10 min): Issue winter weather products.

(30 min): Deterministic model analysis - Ingredients based methodology for forecasting heavy precipitation.

• The trainee should keep in mind the Goree/Younkin/Browne Technique that was presented in simulation 1 as he or she diagnoses the forecast using the deterministic and ensemble operational model guidance in the WES. If the trainee needs more information on the ingredients based methodology for forecasting heavy precipitation, they should see IC Winter Lesson 6.4.

• The trainee should be able to determine the dominant precipitation type across the LSX CWA.

• The trainee should be able to diagnose the synoptic-scale pattern and determine if it is favorable for warning criteria snowfall in the LSX CWA.

• The trainee should be able to apply the ingredients based method for forecasting heavy precipitation by identifying the areas of synoptic-scale forcing using synoptic-scale fields, levels of maximum frontogenesis, areas of low-level frontogenesis and stability, and regions where the front interacts with the upper level wave.

Discussion Points

- Despite slight differences in the mass fields, wind fields, and QPF from the deterministic models, the trainee should be aware that the synoptic fields in the current forecast continue to resemble the conditions that are favorable for heavy snow in the LSX CWA.

- On the 0000 UTC 31 January 2008 model runs, the 500-mb shortwave deepens and transitions from positive to negative tilt as it moves into the LSX CWA from the southwest between 1800 UTC 31 January 2008 and 0000 UTC 1 February 2008. This increased the synoptic-scale forcing over the LSX CWA through the period.

- The level of maximum frontogenesis is best examined using a cross section from northwest Iowa southeastward through the LSX CWA to northeast Alabama. Positive frontogenesis was observed from the surface through 300 mb around 0600 UTC 1 February with the highest values between 700 and 600 mb over the eastern portion of the LSX CWA.

- While examining the same cross section described above, the frontogenesis and equivalent potential vorticity analysis showed that the ascending branch of the frontogenetical circulation was collocated with a large area of reduced stability (EPV ≤ 0.25) between 700 and 500 mb over southern Illinois and the southeastern portion of the LSX CWA. This situation is favorable for increased vertical motion and banded snowfall as the instability acts to modulate the breadth and magnitude of the direct thermal circulation.

- At 0600 UTC 1 February, synoptic-scale forcing and in-situ low- to mid-level mesoscale forcing was responsible for strong vertical motion through a deep layer of the troposphere.

(15 min): Mesoscale diagnosis: TROWAL.

- This section utilizes IC Winter 5 Lesson 5.5 - Structure of TROWALS.

- Using isentropic fields with pressure and winds plotted, the trainee should be able to determine the location of the warm conveyor belt and if the westward branch turns cyclonically around the cyclone.

- The trainee should be able to determine if banded snow is possible within the deformation snow shield and if convection will be slanted or upright.

Discussion Points

- The warm conveyor belt can be seen on the 295 or 300 K isentropic surface when viewing isobars and wind barbs. Specifically, the warm conveyor belt is located from the Gulf Coast northward through the Tennessee and Ohio Valleys between 0000 UTC and 1200 UTC 1 February 2008. This is the location of the broad isobar ridge, which can be found on either isentropic surface.

• Between 0900 UTC and 1200 UTC 1 February the cyclonic branch of the warm conveyor belt and TROWAL airstream further developed as a direct result of the deepening of the low- to mid-level circulation. Here, a more organized isobar ridge is located from north-central Illinois south-southwestward to east-central Missouri. As was stated in the Event Overview, the deformation precipitation did not become organized until the TROWAL developed.

• An examination of MUCAPE across the LSX CWA between 0000 and 1200 UTC 1 February 2008 should suggest to the trainee that upright convection and high snowfall rates are possible. Therefore, the intensity of the NAM40 precipitation forecast in the LSX CWA between 0000 and 1200 UTC 1 February 2008 is underdone.

(5 min): HPC internal winter weather product review.

• During the HPC product review, the trainee should review the most recently issued HPC deterministic snow forecast at 0639 UTC 31 January 2008 and the previous forecast at 1825 UTC 30 January 2008.

• The trainee should determine if there are any major differences between the current and previous HPC forecasts.

• The trainee should keep in mind the previous but more importantly the current HPC forecast when completing the remainder of this simulation.

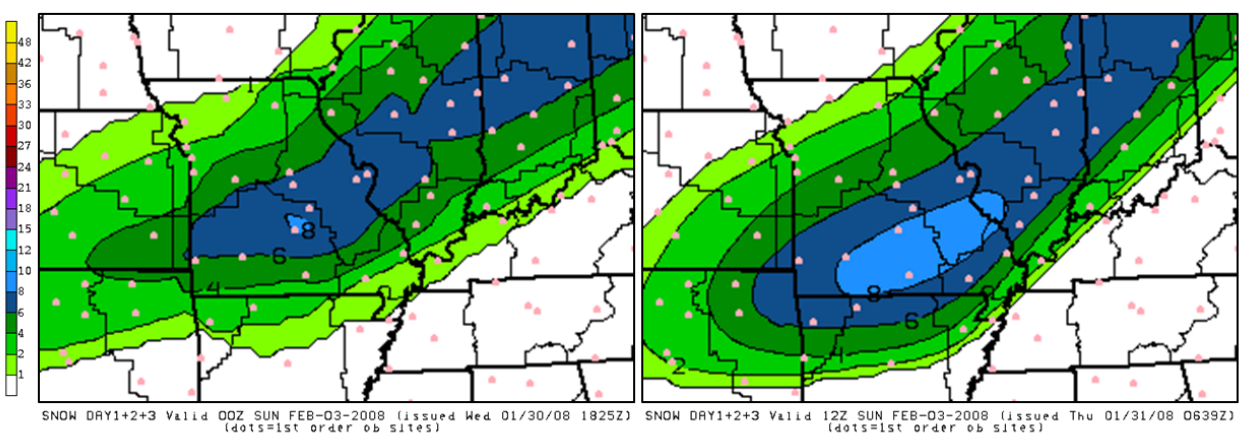

Fig. 2.6 HPC Winter Weather Desk deterministic forecasts issued at 1825 UTC 30 January 2008 (left) and 0639 UTC 31 January 2008 (right).

Discussion Points

• In the most recent HPC deterministic forecast, the forecast snow band placement and amounts have remained consistent. However, there is now a greater than 8” contour over southern portions of the LSX CWA.

(10 min): Issue winter weather products.

• The trainee should determine if all or portions of the LSX CWA should be considered for a winter storm warning or winter weather advisory. In addition to outlining the counties to be included in the winter storm warning or winter weather advisory, the trainee should draw their forecast snowfall amounts. Winter storm warning and winter weather advisory criteria is provided in the appendix for the LSX CWA.

Discussion Points

• Based on the information in this simulation, the trainee should considering issuing winter storm warnings or winter weather advisories for the LSX CWA. Model guidance continues to depict favorable conditions for heavy snow within the LSX CWA. Synoptic-scale features, mesoscale features, and thermodynamic profiles all point to heavy snowfall, especially in the central and northeastern portions of the LSX CWA where a winter storm warning should be considered.

3. Additional Information

The simulation guides can be downloaded online at
www.crh.noaa.gov/lsx/?n=wes_2008jan31

The SOO, ITO, or AWIPS focal point will need to load the cross section procedure Winter_X_Section included on the DVD.

WES Case Install Instructions:
Insert the DVDs into the DVD-ROM. Run the script named install-20-08Jan31-LSX.csh provided on the disks as user fxa. This script will automatically run localizations using the provided custom files. There are 4 disks total and will use approximately 46 GB of space.

The NWP model output included with the winter weather simulation is from 0000 UTC 30 January 2008 and 0000 UTC 31 January 2008.

Disk 1:
customFiles
userPrefs
radar
redbook
sat

Disk 2:
GRID130
GRID185
GRID236
LATLON
LDAD
MSAS
NHEM201
point

Disk 3:
CONUS211
CONUS212 Eta, SREF
CONUS213
CONUS215
GRID218

Disk 4:
CONUS212 GFS

4. References

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Appendix A: Storm Reports

A.1 LSX CWA Storm Data Entries

1. Missouri Counties: Lincoln, St. Charles

Time (UTC): 31 January 1800 UTC - 1 February 1000 UTC

Storm Characteristic: Heavy Snow

Description: A winter storm dropped up to 11 inches of snow across parts of East Central Missouri and Southwest Illinois. Light snow started on Thursday by midday, 1/31/2008, and continued through the day. Amounts were light into Thursday evening, generally from two to four inches. Late Thursday night into the early morning hours Friday, 2/1/2008, heavy snow developed with snow falling at the rate of two to three inches per hour.

2. Illinois Counties: Bond, Calhoun, Clinton, Fayette, Greene, Macoupin, Marion, Montgomery, and Washington

Time (UTC): 31 January 1800 UTC - 1 February 1000 UTC

Storm Characteristic: Heavy Snow

Description: A winter storm dropped up to 11 inches of snow across parts of East Central Missouri and Southwest Illinois. Light snow started on Thursday by midday, 1/31/2008, and continued through the day. Amounts were light into Thursday evening, generally from two to four inches. Late Thursday night into the early morning hours Friday, 2/1/2008, heavy snow developed with snow falling at the rate of two to three inches per hour.

Appendix B: Winter Weather Products and Criteria

B.2 LSX CWA Winter Weather Products and Criteria

Winter Storm Watch: A watch is used when the risk of hazardous winter weather has increased significantly, there is a strong possibility it will reach warning criteria, and falls in the 12 to 48 hour portion of the forecast.

Winter Storm Warning: Issued for snow events of 6 inches or more, sleet accumulations of 1/2 inch or more, or a combination of winter precipitation which will create life threatening conditions.

Winter Weather Advisory: Issued for average snowfall of 3 to 5 inches, sleet accumulation of less than 1/2 inch, or a combination of winter precipitation which will produce hazardous conditions. At forecaster discretion, an advisory can be issued for lesser amounts of snowfall if the timing of the event creates hazardous conditions.

Appendix C: Supplemental Materials

SYNOPTIC CLIMATOLOGY OF HEAVY SNOWFALL OVER THE CENTRAL AND EASTERN UNITED STATES

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ABSTRACT

Verification shows that recent guidance and official heavy snowfall forecasts have achieved only a modest degree of success. Therefore, the synoptic-climatological relationship of heavy snowfall to those surface and upper-air features which are routinely forecast is studied in an attempt to improve operational forecasting of heavy snowfall east of the Rockies. The relationship is modeled in a way suitable for direct use on available circulation prognoses. The models relate percentage frequency of occurrence of heavy snowfall in 12-hr. periods to the initial 500-mb. absolute vorticity maximum, the 500-mb. height contours, the 1000–500-mb. thickness contours, and the surface low pressure center.

1. INTRODUCTION

The prediction of heavy snow is one of the Weather Bureau's most important functions, yet on the average, only a modest degree of success can be claimed. During the winter seasons of 1962–63, 1963–64, and 1964–65 heavy snow guidance forecasts for the entire United States were issued by the Quantitative Precipitation Forecast (QPF) Section of the National Meteorological Center (NMC). These forecasts were verified along with those issued by Forecast Centers with designated responsibility for areal heavy snow forecasting. The usual definition of heavy snow as 4 in. or more in 12-hr. time intervals was used. Verification intervals were only for the specific time periods of 0000 to 1200 GMT and 1200 to 0000 GMT. All forecasts verified were completed at an average time of approximately three hours before the beginning time of the forecast periods. The sizes of areas forecast and observed were measured in square degrees of latitude by planimeter and compared by "threat score." "Threat score" is defined as

$$\frac{A_c}{A_f+A_o-A_c}$$

where A_c=area correct, A_f=area forecast, and A_o=area observed.

Table 1 shows that over the three-season period only 12 percent of the total area of heavy snow forecast and observed was correctly forecast. The total of the area alerted in advance for heavy snow that did not occur and of the area observing heavy snow that was not forecast was a little more than seven times the area correctly forecast. These statistics indicate the need for further refinement of heavy-snow forecasting techniques. In view of the increasing accuracy of the products of numerical weather prediction, new models relating upper-air circulation features to occurrence of heavy snow are needed.

TABLE 1.—*NMC's guidance and Field Centers' official heavy snowfall areas (in square degrees of latitude) forecast (A_f), observed (A_o), and correct (A_c), and the corresponding "threat score" for the winters of 1962 through 1965. Note that numerical value of A_o is doubled since two sets of forecasts are verified as an entity*

Season	A_f	$2(A_o)$	A_c	Threat score
1962–63	2642.1	908.8	352.7	0.110
1963–64	1858.5	980.8	313.8	.124
1964–65	1617.3	1127.4	341.6	.142
Total	6117.9	3017.0	1008.1	.124

Fawcett and Saylor's [1] recent synoptic-climatological models of weather accompanying Colorado-type storms are proving extremely valuable in heavy-snow forecasting for the northern Rockies and Plains. A similar approach is followed in this study in developing relationships for use in forecasting the more important snow storms for that area of the United States east of the Rocky Mountains. The models developed present the synoptic climatology of heavy snow situations in terms of features of surface and upper-air circulation prognoses prepared on a regular basis at NMC.

2. PROCEDURE

The original set of data consisted of all heavy snow situations during the 1963–64 and 1964–65 seasons for that area of the United States east of 100° W., including that portion of Canada south of 49° N. and west of the northern tip of Maine. Heavy snow, as defined for this study, is snowfall of 4 in. or more over a minimum area of 4 square degrees of latitude (14,384 n. mi.^{2}) in the specific 12-hr. periods from 0000 to 1200 GMT or 1200 to 0000 GMT. There were 81 cases in the two seasons that met these qualifications. Fifty of these were associated with deepening and occluding surface low-pressure systems. This characteristic is common to all snowstorms

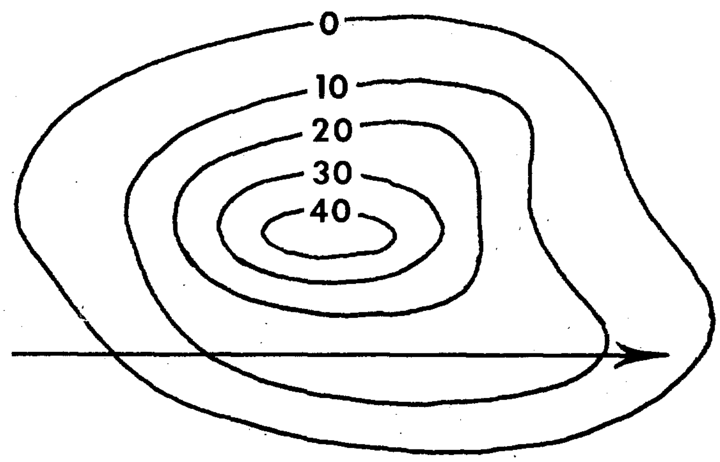

FIGURE 1.—Percentage frequency of occurrence of heavy snow with respect to the initial vorticity maximum and the direction of movement of the vorticity maximum during the following 12 hr. Origin is at initial position of vorticity maximum. Average direction and speed of movement of vorticity center, 61° at 35 kt. Scale 1:20,000,000.

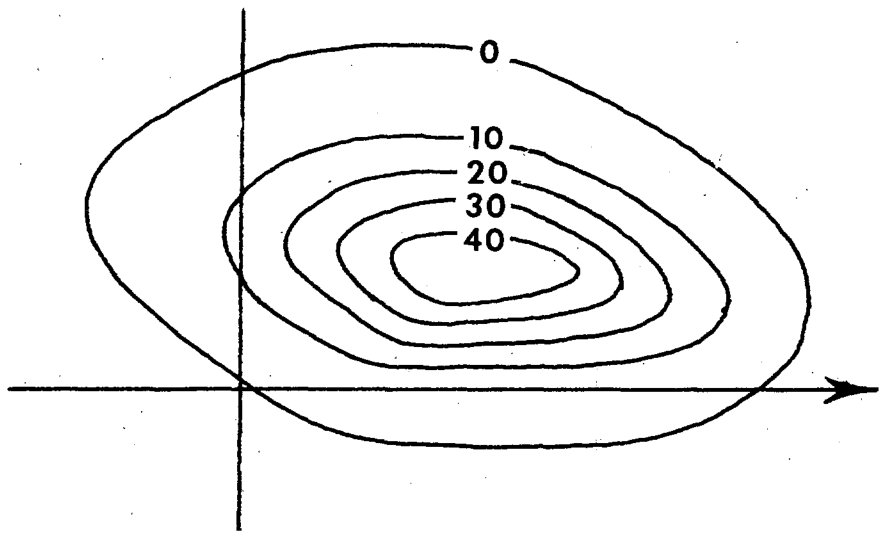

FIGURE 2.—Percentage frequency of occurrence of heavy snow with respect to the initial surface low center and the direction of movement of the center during the following 12 hr. Origin is at initial position of surface Low. Average direction and speed of movement of low center, 50° at 31 kt. Scale 1:20,000,000.

that reach severe intensity in the central and eastern United States. This study deals mainly with these more important weather situations (50 cases) unless it is specifically stated otherwise.

The relationship of 12-hr. heavy snowfall to selected circulation parameters at the beginning of the snowfall period was obtained in the following manner. First, a grid overlay with grid-interval of ¼ degree of latitude was placed over the observed heavy snow area in such a way that the origin was at the position of the initially observed 500-mb. vorticity maximum[1] with x-axis oriented in the direction of its observed position at the end of the 12-hr. snowfall period. Second, the occurrences of heavy snow in each grid square were tallied for all 50 cases and a smoothed analysis (fig. 1) made of percentage frequency.

Figure 2 was derived in the same manner, except the grid origin was placed at the initial observed surface low-pressure center with x-axis oriented in the direction of its observed position at the end of the 12-hr. snowfall period.

Figures 3 and 4, showing composite 500-mb. height and 1000–500-mb. thickness features, were derived similarly, except height and thickness values were tallied on a coarser grid (each square equal to 2 square degrees of latitude) before mean values were analyzed. Figures 3 and 4 were used to derive the composite 1000-mb. chart shown in figure 5. Superimposed on the composite charts (figs. 3, 4, and 5) is the percentage frequency of heavy snow as related to the vorticity maximum from figure 1.

[1] The 500-mb. vorticity analyses were obtained from the NWP barotropic prognoses with data cutoff at 1 hr. and 30 min. after regular upper-air observation time.

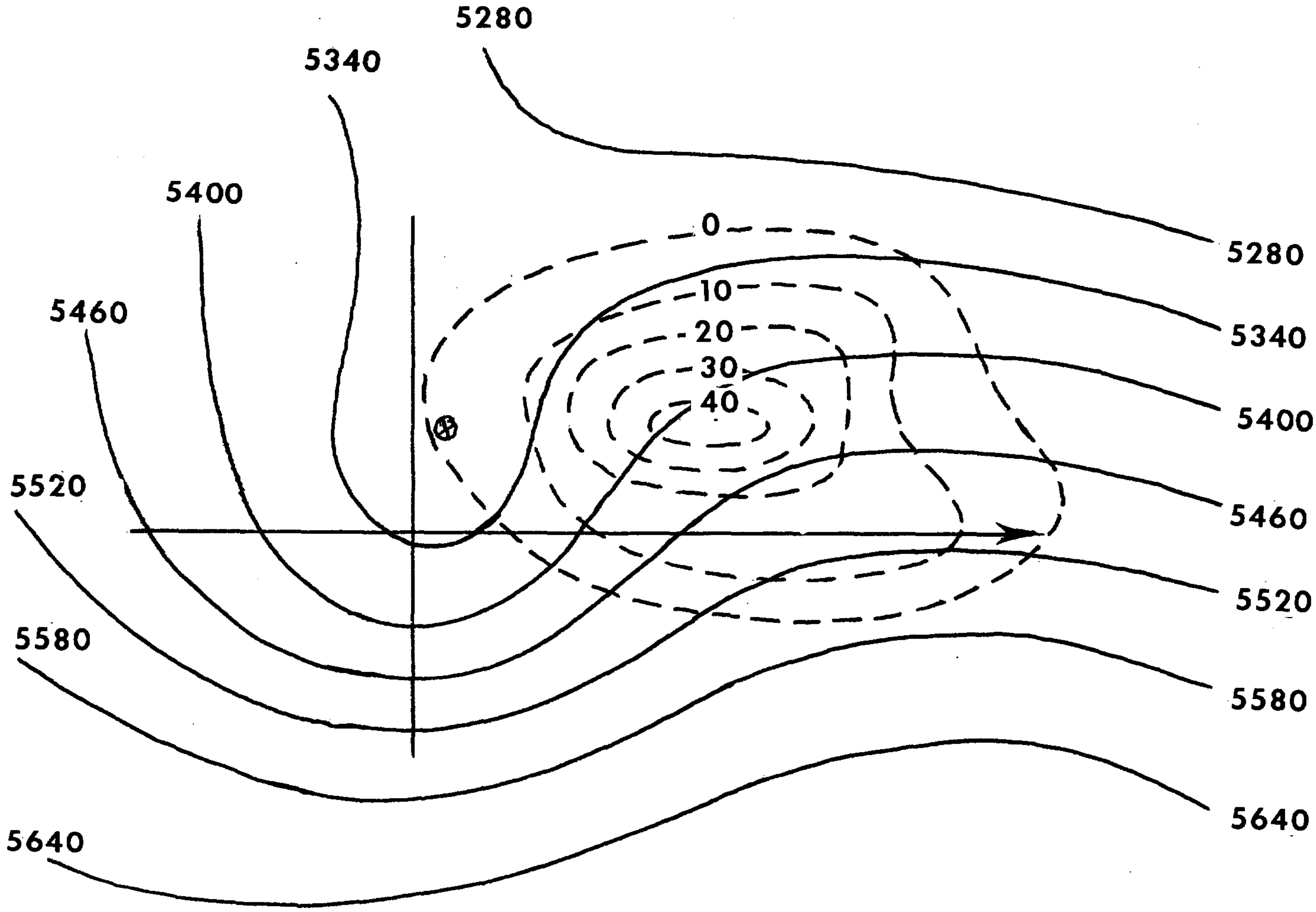

FIGURE 3.—Percentage of occurrence of heavy snow and composite initial 500-mb. chart (gpm.). Orientation is the same as figure 1 Scale 1:20,000,000.

3. DISCUSSION OF RELATIONSHIPS

Figures 1 through 5 indicate certain favored locations for the occurrence of heavy snow. The most favorable location with respect to the 500-mb. vorticity maximum is about 6.5 to 7 latitude degrees downstream and 2.5 latitude degrees to the left of the track of the maximum during the following 12 hr. The favored location with respect to the surface low-pressure center is about 5 latitude degrees along and 2.5 latitude degrees to the left of its path. This is in good agreement with Fawcett and Saylor's [1] findings about heavy snow associated with the Colorado-type cyclone. From the composite 500-mb. chart in figure 3, the best location for heavy snow is along the path of the 500-mb. Low and slightly downstream from the point where contour curvature changes from cyclonic to anticyclonic. Figure 4 shows heavy snow is most likely near the thickness ridge within the contour interval 5310 to 5370 gpm. The heavy snowfall distribution with the derived composite 1000-mb. chart in figure 5 is very similar to that shown in relation to the surface low center (fig. 2).

It is well known that the polar jet is often intimately associated with the occurrence of heavy snow. The model relationship for 40 cases (27 of these qualified as deepening and occluding low-pressure systems) during the 1963–64 season is shown in figure 6. The individual jet for each of these cases was delineated through careful consideration of observed 200- and 300-mb. data and 25,000- to 40,000-ft. winds. Further attempts to model the jet relationship to heavy snow were discontinued during the 1964–65 season. It was found that the available forecasting tools were incapable of predicting the location of the jet to a suitable degree of accuracy. Therefore, the model was found to be of limited forecast value.

4. ADDITIONAL DATA

Table 2 lists in order of areal rank the snowstorms with areal extent of 20 square degrees of latitude or greater. All nine of these were of the deepening and occluding type. The average areal extent for the original data set of 81 cases was 10.0 square degrees of latitude, while that for the 50 deepening and occluding cases was 11.9. Table 2

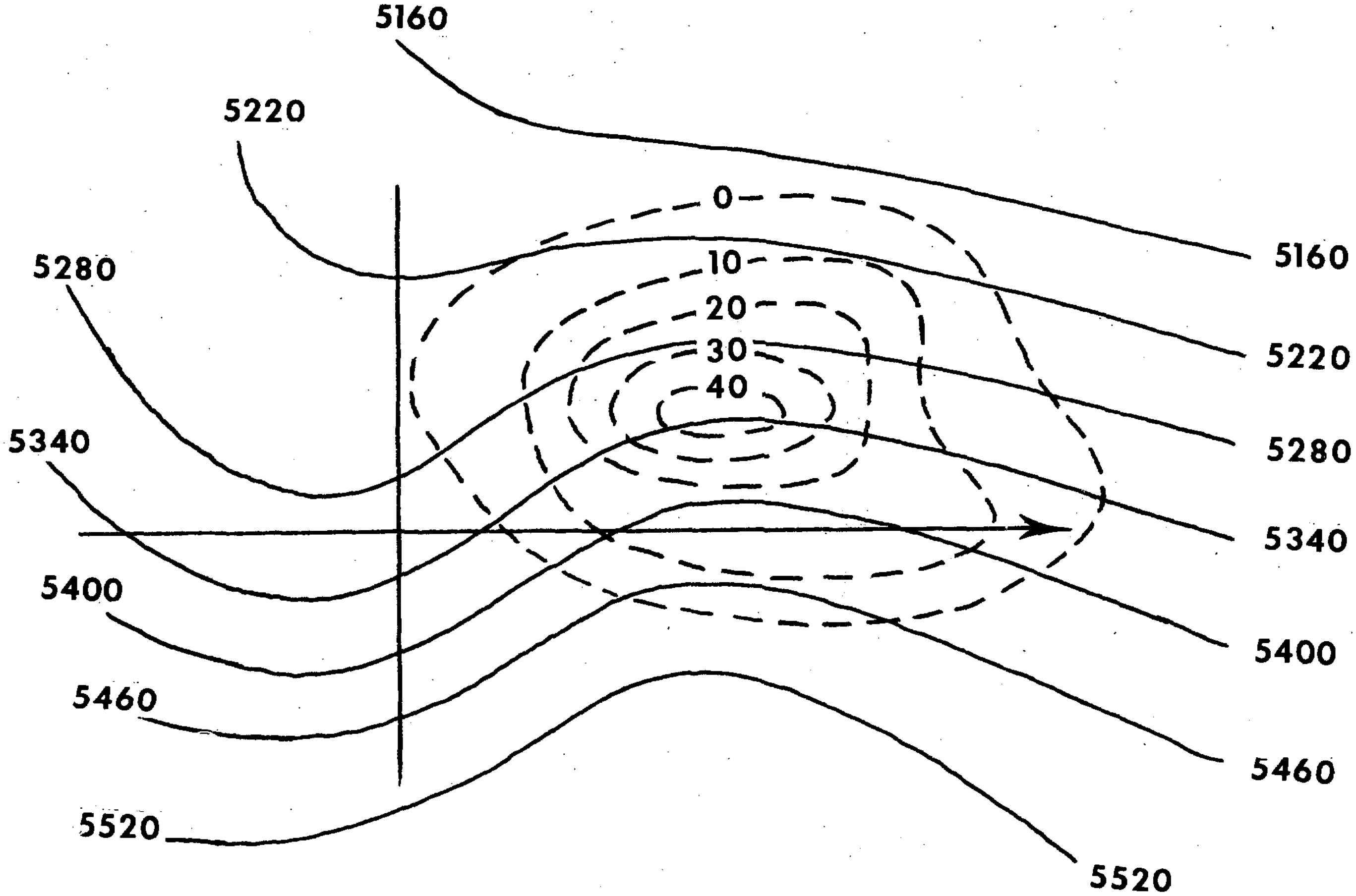

FIGURE 4.—Percentage frequency of occurrence of heavy snow and composite initial 1000–500-mb. thickness chart (gpm.). Orientation is the same as figure 1. Scale 1:20,000,000.

also lists the values of the vorticity maxima at 500 mb. associated with these top-ranking storms. It is clearly evident that a strong vorticity maximum is a prime requisite for the occurrence of heavy snowfall of major proportions.

Table 3 gives frequency distributions of a number of meteorological measurements for the 50 deepening and occluding cases. The average value of the vorticity maximum was 19.8×10^{-5} sec.$^{-1}$ (range 13.8 to 24.8), while that for the top-ranking cases was 21.7×10^{-5} sec.$^{-1}$. The average speed of movement of the vorticity maximum was 35 kt., while the average direction of movement was toward 61°. Only six cases occurred with movement of the maximum toward due east, or south of east; in the other 44 cases, this movement was in a direction north of east. The mean lowest observed 500-mb. temperature within a distance of 3° latitude from the vorticity maximum was −30° C. The lowest temperature was −36° C. and the highest was −21° C. The average speed of movement of the surface low-pressure center was 30 kt., while the average direction of movement was toward 50°. All except three surface Lows moved in a direction north of east.

Table 4 provides information on areal extent of heavy snowfall and strength of vorticity maxima for the entire set of 81 heavy snow situations.

TABLE 2.—*Top-ranking snowstorms and values of associated 500-mb. vorticity maxima. Date and time are for the beginning of the 12-hr. snowfall period. Area is in square degrees of latitude*

Rank	Date	Time (GMT)	Area	Vorticity ($\times 10^{-5}$ sec.$^{-1}$)
1	2-25-65	1200	26.0	23.8
2	3-17-65	1200	25.8	18.1
3	1-13-64	0000	24.0	21.4
4	1-13-64	1200	23.5	24.0
5	1- 1-64	0000	23.5	20.0
6	2-26-65	0000	23.3	21.5
7	2-25-65	0000	21.8	20.9
8	2-12-65	0000	20.3	21.0
9	1- 1-64	1200	20.0	24.8

5. ADDITIONAL COMMENTS ON FORECASTING SNOWFALL

Although precipitation is the net result of many and complex interacting atmospheric processes, it is convenient to classify snowfall situations as to the main causal sources of upward motion. Storm precipitation may be thought of as the net yield of the producing capacity of the storm itself and the contribution which results from orographic effects. For that area of the United States under consideration and for the scale of the systems under study, we are primarily interested in the first of these components which is a direct function of the atmospheric dynamics

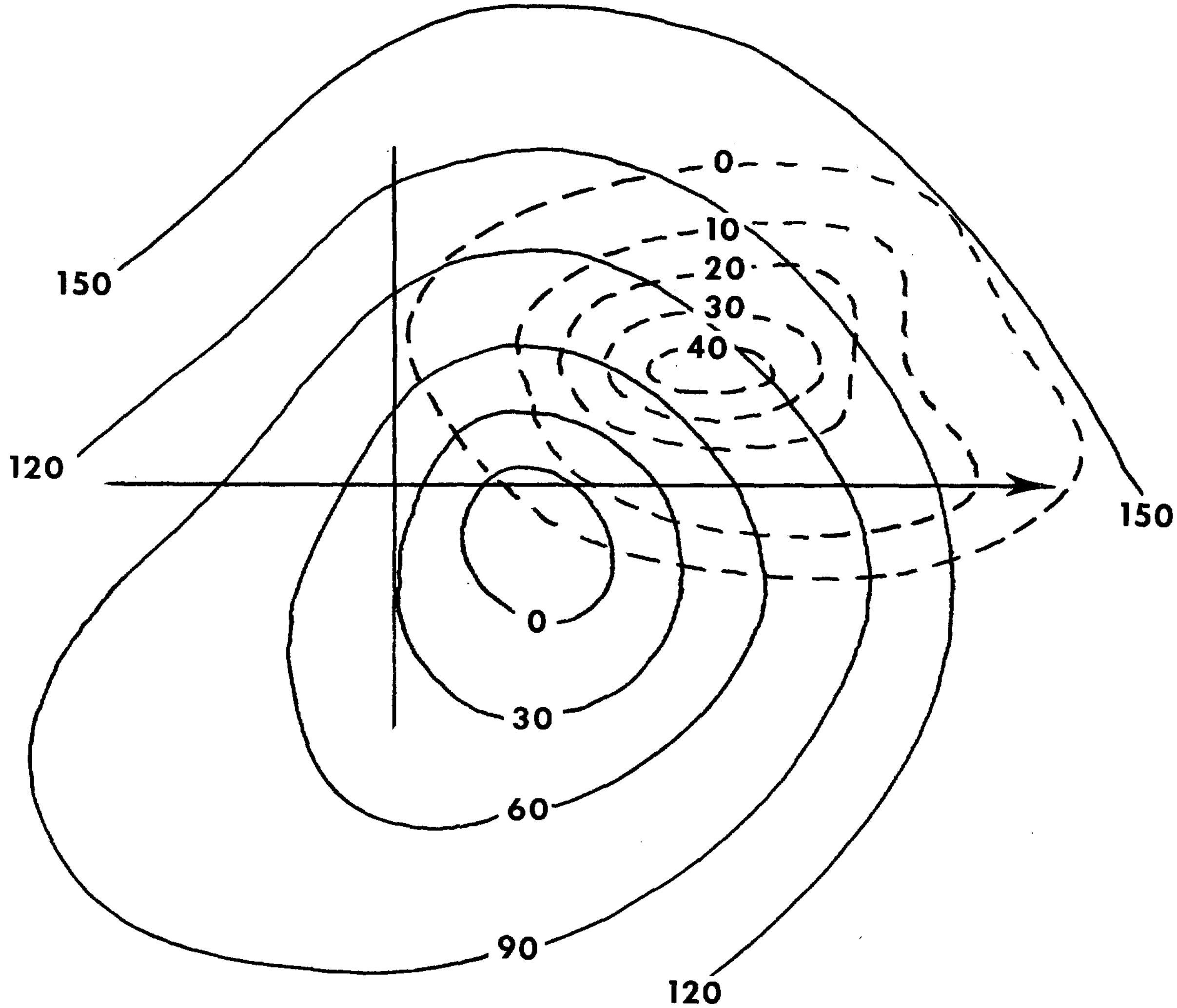

FIGURE 5.—Percentage frequency of occurrence of heavy snow and the initial 1000-mb. chart (gpm.), derived from the composite 500-mb. and 1000–500-mb. thickness charts. Orientation is the same as in figures 1, 3, and 4. Scale 1:20,000,000.

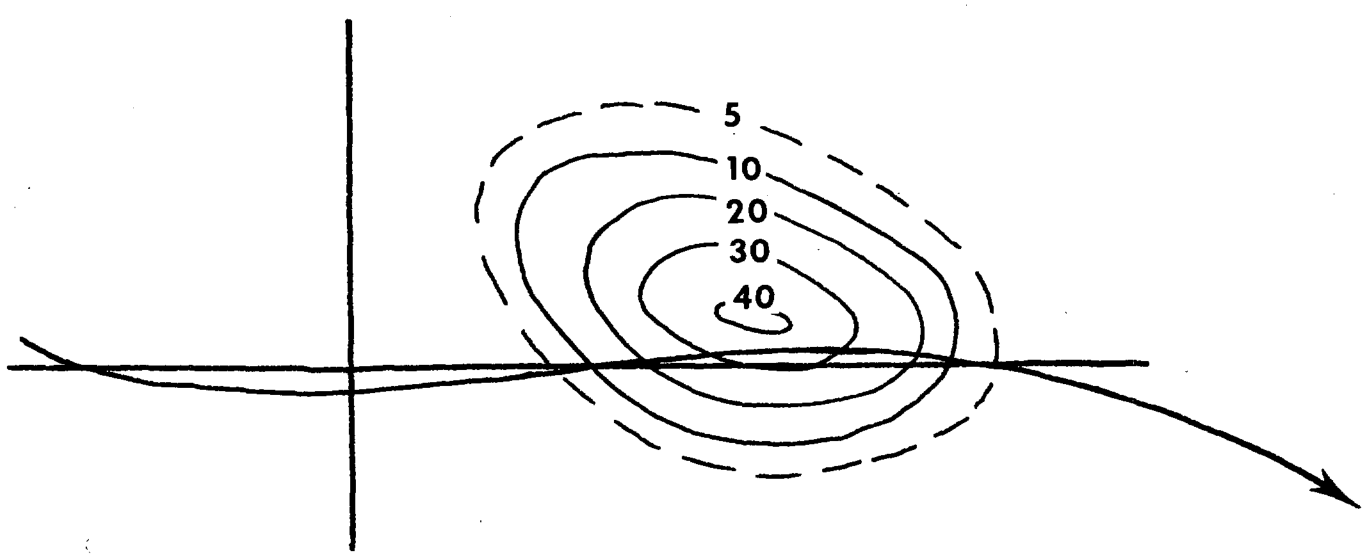

FIGURE 6.—Percentage frequency of occurrence of heavy snow with respect to the initial position of the jet stream. The x-axis is oriented along the jet and the y-axis passes through the position of the 500-mb. vorticity maximum. 40 cases 1963–64 season. Scale 1:20,000,000.

producing upward air motion. In identifying the dynamic processes creating vertical motion systems in the atmosphere, a conventional simplification is to assume geostrophic conditions. Then the vertical motions are dependent upon temperature advection (Laplacian of the temperature advection) and vorticity advection (vertical gradient of absolute vorticity advection). Warm advection (WA) and positive vorticity advection (PVA) generate upward motion, while cold advection (CA) and negative vorticity advection (NVA) generate downward motion.

TABLE 3.—*Frequency distributions—number of cases each season and two-season percentage frequency of occurrence. (Deepening and occluding type systems only).*

a. Value of absolute vorticity maximum at 500 mb. ($\times 10^{-5}$ sec.$^{-1}$)

Period	12.5–14.9	15.0–17.4	17.5–19.9	20.0–22.4	22.5–24.9
1963–64	0	3	7	11	6
1964–65	3	3	8	7	2
Two Seasons (%)	6	12	30	36	16

b. Speed of vorticity maximum at 500 mb. (kt.)

	10–19	20–29	30–39	40–49	50–59
1963–64		5	14	8	
1964–65	3	4	9	4	3
Two Seasons (%)	6	18	46	24	6

c. *Direction of movement of 500-mb. vorticity maximum (to nearest 10° of arc from N.)*

	20	30	40	50	60	70	80	90	120	150
1963–64			3	7	6	7	2	1	1	
1964–65	1	3	4	5	3	2	1	2	1	1
Two Seasons (%)	2	6	14	24	18	18	6	6	4	2

d. Lowest 500-mb. temperature within 3° latitude distance of vorticity maximum (Below 0°C.)

	20–24	25–29	30–34	35–39
1963–64	2	12	7	6
1964–65	4	7	10	2
Two Seasons (%)	12	38	34	16

e. Speed of surface low-pressure center (kt.)

	10–19	20–29	30–39	40–49	50–59
1963–64	3	5	13	4	2
1964–65	3	9	10	1	
Two Seasons (%)	12	28	46	10	4

f. Direction of movement of surface low-pressure center (to nearest 10° of arc from N.)

	0	10	20	30	40	50	60	70	80	90	100	120
1963–64		2	1	3	5	6	4	2	3	1		
1964–65	1	1	1	4	1	5	4	4			1	1
Two Seasons (%)	2	6	4	14	12	22	16	12	6	2	2	2

g. Areal extent of heavy snowfall (Sq. degrees of lat.)

	4.0–7.9	8.0–11.9	12.0–15.9	16.0–19.9	20.0–23.9	24.0–27.9
1963–64	8	3	10	2	3	1
1964–65	11	4	2	1	3	2
Two Seasons (%)	38	14	24	6	12	6

TABLE 4.—*Frequency distributions—number of cases each season and two-season percentage frequency of occurrence. (All 81 cases)*

a. Value of absolute vorticity maximum at 500 mb. 10^{-5} sec.$^{-1}$

Period	10.0–12.4	12.5–14.9	15.0–17.4	17.5–19.9	20.0–22.4	22.5–24.9
1963–64			8	12	13	7
1964–65	3	7	4	14	11	2
Two Seasons (%)	4	8	15	32	30	11

b. Areal extent of heavy snowfall (Sq. degrees of lat.)

	4.0–7.9	8.0–11.9	12.0–15.9	16.0–19.9	20.0–23.9	24.0–27.9
1963–64	17	5	11	3	3	1
1964–65	27	6	2	1	3	2
Two Seasons (%)	54	14	16	5	7	4

It is common procedure in the QPF Section to classify snowfall as to its main dynamic source of upward motion, that is, WA-type snowfall or PVA-type snowfall. There are individual cases when snowfall is related completely to concurrent WA, while at other times it is completely related to concurrent PVA. However, the common occurrence is for the presence of both WA and PVA through a broad spectrum of variance in intensity of each. The presence of both is required to a considerable degree of intensity (considering the entire tropospheric layer) for the production of upward motion sufficient for major snowstorms. The main operational value of these synoptic-climatological models in forecasting heavy snowfall stems from their providing a quick assessment of circulation prognoses in terms of location of the most suitable environment (WA, PVA, and moisture) for production of heavy snowfall.

6. SUMMARY

The models developed present percentage frequency of occurrence of heavy snowfall in relation to selected circulation features for 50 important snowfall situations in the central and eastern United States. All these cases were commonly characterized by deepening and occluding surface low-pressure systems. These models can be used to determine quickly and objectively the most favorable location for occurrence of heavy snowfall, given a set of prognoses. This quick assessment of the forecast situation allows more time for the forecaster to deal with details (such as direction and speed of movement of vorticity maximum and surface low-pressure center, deepening of the 500-mb. and surface systems, delineation of the rain versus snow line, etc.) in predicting a reasonable and consistent pattern of heavy snowfall.

ACKNOWLEDGMENTS

We wish to thank Mr. E. B. Fawcett and Mr. H. K. Saylor of the Analysis and Forecast Division of NMC for providing many helpful suggestions.

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1. E. B. Fawcett and H. K. Saylor, "A Study of the Distribution of Weather Accompanying Colorado Cyclogenesis," *Monthly Weather Review*, vol. 93, No. 6, June 1965, pp. 359–367.

[*Received June 9, 1966; revised September 12, 1966*]

UDC 551. 578. 45. 551. 509. 314: 551. 515. 127

SOME RELATIONSHIPS BETWEEN 850-MILLIBAR LOWS AND HEAVY SNOW OCCURRENCES OVER THE CENTRAL AND EASTERN UNITED STATES

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ABSTRACT

It is generally known that certain relationships exist between the production of heavy snow and low-level dynamic and thermodynamic parameters, such as vorticity, moisture, and temperature advection patterns. This statistical synoptic climatological study at the 850-mb level is made to understand better these relationships and also to improve operational forecasting of heavy snow over the central and eastern United States. Models relating percentage frequency of heavy snowfall in 12-hr periods to initial and subsequent 850-mb height and temperature patterns are developed. Also, considerable other statistical information is arranged in tabular form for forecaster evaluation.

1. INTRODUCTION

The 850-mb chart long has been a favorite tool of forecasters in forecasting occurrence of precipitation, especially snow. Recently, Hanks et al. (1967) made considerable use of 850-mb observed data in developing a technique for predicting heavy snowfall in the central United States and Spiegler (1969) studied snowfall distribution and frequency about 850-mb cyclones. In view of the pertinence of observational information at this level to forecasting snowfall, data on certain relationships between 850-mb features and occurrence of heavy snowfall have been systematically tabulated and summarized.

2. PROCEDURES

Developmental data consisted of 81 heavy snow occurrences during the 1965-66 and 1966–67 snowfall seasons for the area of the United States east of 100° W., including that portion of Canada south of 49° N. and west of the northern tip of Maine. Complete data for the month of December 1965 were not available; therefore, this month was not included in the study. Heavy snow, as defined in this study, is snowfall of 4 in. or more over a minimum contiguous area of 5 square degrees of latitude (about 17,982 n.mi.^{2}) during the 12-hr periods from 0000 to 1200 GMT or 1200 to 0000 GMT. When an observed heavy snowfall area overlapped the boundaries of the area of interest, the case was used if an importantly large proportion fell within the defined boundaries.

The moving grid was used in relating heavy snowfall to 850-mb synoptic features in a manner similar to that used by Jorgensen (1963) and Fawcett and Saylor (1965). This method related heavy snowfall to the location of the 850-mb low center at the beginning of the snowfall period and its direction of movement during the subsequent 12-hr period—identical to that used by Goree and Younkin (1966) and Younkin (1968) in relating heavy snowfall to 500-mb vorticity maxima. The position of the 850-mb low center served as the basic anchoring coordinate in obtaining relative distribution of heavy snowfall occurrences. The direction of movement was obtained from the observed positions of the Low at the beginning and end of the 12-hr period during which the heavy snow occurred. There was only one instance of heavy snowfall occurrence as defined above in which an 850-mb low center was not discernible.

3. DISCUSSION OF RELATIONSHIPS

Figures 1 and 2 indicate favored locations for occurrence of heavy snowfall in relation to the various parameters at the beginning and end of the snowfall period, respectively. Even though these composite charts show warm advection to be a major contributor to the upward motion producing heavy snow, there is a net slight cooling during the 12-hr period in the region of heavy snowfall.

Tables 1 and 2 give frequency distributions, for the 81 cases, of a number of meteorological measurements. The average direction and speed of movement of the 850-mb low center, 68° at 26 kt, compares with average values for the surface low center of 50° at 31 kt obtained by Goree and Younkin (1966) from an earlier set of data. A northward component in the direction of movement of the 850-mb center was observed in 75 of the 81 cases. Again, this agrees well with the earlier study in that importantly large snowstorms in the central and eastern United States usually move from a southerly direction.

Heavy snow fell during the ensuing 12-hr period at locations with 850-mb temperature as low as −20°C and as high as 5°C. The average temperature at the initial 850-mb low center for all cases was approximately 0°C, while 63 percent of the time this temperature fell between −5°C and 4°C. The 850-mb isotherm that bisected the ensuing heavy snowfall areas averaged approximately −5°C. In 94 percent of the cases, this initial bisecting isotherm was in the −10° to 0°C range.

The average height value of the 850-mb low center at the beginning of the 12-hr snowfall period was 1280 gpm. The central height values varied over a broad range from 1090 to 1470 gpm, with 82 percent of the cases

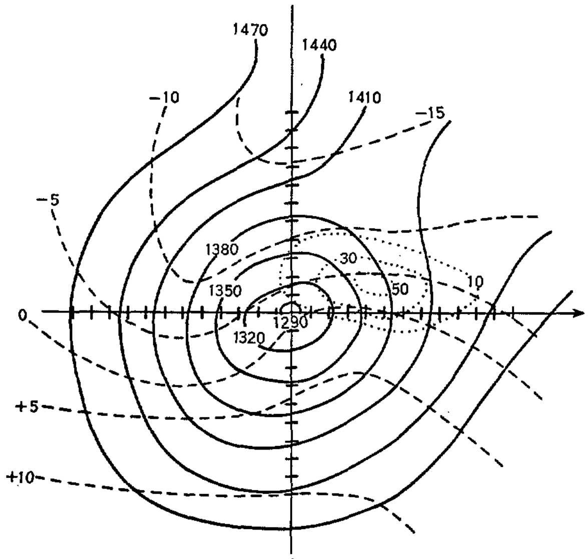

FIGURE 1.—Percentage frequency of occurrence of heavy snow (dotted lines), composite initial 850-mb height (gpm, solid lines) and temperature (°C, dashed lines). Origin is at the position of the 850-mb low center at the beginning of the snowfall period, with horizontal coordinate pointing in the direction of its movement during the following 12 hr. Tick marks on coordinates represent degrees of latitude.

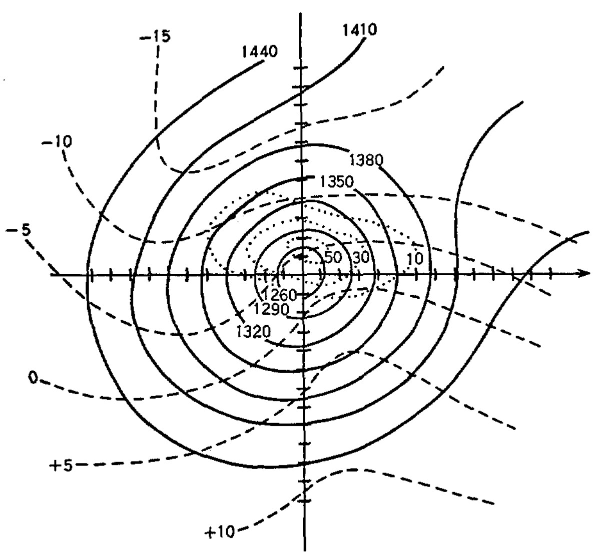

FIGURE 2.—Percentage frequency of occurrence of heavy snow (dotted lines), composite final 850-mb height (gpm, solid lines) and temperature (°C, dashed lines). Origin is at the position of the 850-mb low center at the end of the snowfall period, with horizontal coordinate pointing in the direction of its movement during the preceding 12 hr. Tick marks on coordinates represent degrees of latitude.

falling in the wide interval of 1150 to 1390 gpm. The height contour bisecting the ensuing heavy snowfall area ranged from 1180 to 1540 gpm. The bisecting-contour grouping also had a rather flat distribution pattern, with 67 percent of the cases in the broad range from 1300 to 1440 gpm. Deepening of the 850-mb low center occurred during the 12-hr snowfall period in 94 percent of the cases. The average deepening was approximately 50 gpm.

TABLE 1.—*Frequency distributions, number of cases and percentage frequency of occurrence. Estimated values are from the observed 850-mb charts at the beginning of 12-hr heavy snowfall periods.*

(A) Areal extent (sq deg of lat.) of heavy snowfall cases

	5–9	10–14	15–19	20–24	25–29	30–34	35–40
No. cases	26	18	5	10	14	5	3
Percent	32	22	6	12	17	6	4

(B) Height value (to nearest 10 gpm) of 850-mb low center

	1050–1090	1100–1140	1150–1190	1200–1240	1250–1290	1300–1340	1350–1390	1400–1440	1450–1490
No. cases	1	4	12	12	14	13	15	9	1
Percent	1	5	15	15	17	16	19	11	1

(C) Height contour (to nearest 10 gpm) at 850 mb bisecting heavy snowfall area

	1050–1190	1200–1240	1250–1290	1300–1340	1350–1390	1400–1440	1450–1490	1500–1540
No. cases	1	2	11	14	23	18	9	3
Percent	1	2	14	17	28	22	11	4

(D) Temperature (°C) at 850-mb low center

	−15 to −11	−10 to −6	−5 to −1	0 to 4	5 to 9	10 to 14
No. cases	3	7	23	28	19	1
Percent	4	9	28	35	23	1

(E) Coldest temperature (°C) at 850 mb over heavy snowfall area

	−20 to −16	−15 to −11	−10 to −6	−5 to −1
No. cases	7	23	35	16
Percent	9	28	43	20

(F) Warmest temperature (°C) at 850 mb over heavy snowfall area

	−10 to −6	−5 to −1	0 to 4	5 to 9
No. cases	6	29	40	6
Percent	7	36	50	7

(G) Isotherm (°C) at 850 mb bisecting heavy snowfall area

	−15 to −11	−10 to −6	−5 to −1	0 to 4
No. cases	4	35	36	6
Percent	5	43	45	7

(H) Direction (to nearest 20° of arc from N.) and distance (deg of lat.) from 850-mb low center to associated surface low center

Distance	30	50	70	90	110	130	150	170	190	210	230	250	310	330	Total
0–1.9	3	2	5	4	6	4	6	5	5	1	1	1	2		45
2.0–3.9	1		3	3	6	6	2	4	1	2	1			1	30
4.0–5.9			1	2		1		1		1					6
No. cases	4	2	9	9	12	11	8	10	6	4	2	1	2	1	81
Percent	5	2	11	11	15	14	10	13	8	5	2	1	2	1	100

(I) Temperature (°C) at 850 mb over associated surface low center

	−10 to −6	−5 to −1	0 to 4	5 to 9	10 to 14
No. cases	3	12	23	26	17
Percent	4	5	28	32	21

TABLE 2.—*Frequency distributions, number of cases and percentage frequency of occurrence. Average values are from the two 850-mb charts at the beginning and ending of the 12-hr heavy snowfall periods.*

(A) Speed of movement (kt) of 850-mb low center

	5-9	10-14	15-19	20-24	25-29	30-34	35-40	41-45	46-50	51-55	56-60
No. cases	5	6	13	12	15	11	11	3	0	3	1
Percent	6	7	16	15	19	14	14	4	0	4	1

(B) Direction of movement (toward and to nearest 10° of arc from N.) of 850-mb low center

	10	20	30	40	50	60	70	80	90	100	110	120	130	300	340
No. cases	4	3	4	9	11	12	19	4	4	3	4	1	1	1	1
Percent	5	4	5	11	14	15	23	5	5	4	5	1	1	1	1

(C) Intensity (gpm) of 850-mb low center—outermost closed height contour (10 gpm) minus central height value (to nearest 10 gpm)

	<50	50-90	100-140	150-190
No. cases	7	33	33	8
Percent	8	41	41	10

The position of the surface low center was recorded for each case; consequently, the slope from the 850-mb low center is included in table 1. Generally, the least slope between the surface low center and associated 850-mb low center occurred during the initial stages of extensive snowfall and when the systems were at lower latitudes. The average slope was 1:125, while the extreme slope was 1:300. The direction of the surface low center from the 850-mb center had a southerly component in all cases except three. In 60 percent of the cases, the surface low center was in the southeast quadrant of the 850-mb Low.

The 850-mb temperature over the surface low center is given in table 1. Since the main moisture inflow with consistently high relative humidity occurs aloft near the position of the surface low center, this temperature information was used to provide an indication of moisture inflow into the system without reference to specific moisture measurements, such as precipitable water, dew points, etc. Also, 850-mb temperature forecasts are available at many Weather Bureau Offices and can be used to infer this parameter. During 53 percent of the time, the 850-mb temperatures over the surface low center at initial time were in the 5° to 14°C range, and 81 percent of the time they were 0°C or higher.

The extent of an analyzed area of observed heavy snowfall in a specific 12-hr period depends also upon factors other than rate of fall and duration: for example, warmth of the ground, time of onset of snowfall within the period, and density of observational network. However, above and beyond these and other meteorologically disturbing factors, there is a sufficiently close relationship between the strength of the 850-mb Low and areal extent of heavy snow to be of some aid in forecasting. A crude measure of the average strength of the 850-mb Low (sum in decameters of the outermost closed contour at the beginning and end of the snowfall period minus central values) minus 6 decameters provides a rough guide as to reasonable extent of snowfall in a 12-hr period in square degrees of latitude.

4. SUMMARY

1) The mean circulation of the 850-mb Lows increased significantly during the 12-hr period of heavy snowfall. Computations of geostrophic relative vorticity (849-km grid) from the composite charts (figs. 1 and 2) yield an increase of 13 percent at the low center. However, at the center of highest percentage occurrence of heavy snow, the increase was nearly fourfold.

2) The highest probability of heavy snow lies approximately 90 n.mi. to the left of the track of the 850-mb low center.

3) Cooling in the rear quadrants of the Low occurs in early stages of development. In the front quadrants of the Low, little warming occurs in spite of substantial warm advection. Apparently, upward motion and precipitation cooling offset advection and latent heat warming.

4) On the average, the initially observed −5°C isotherm nearly bisects the observed subsequent 12-hr heavy snowfall area.

5) The direction of movement of 850-mb low centers during heavy snowfall from a northerly component is an infrequent occurrence.

6) The initially observed 850-mb temperature over the surface low center is above 0°C most of the time when heavy snow occurs during the subsequent 12 hr.

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